A LABORATORY MANUAL IN PHYSICS

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A LABORATORY MANUAL IN PHYSICS

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A LABORATORY MANUAL IN PHYSICS

TO ACCOMPANY

BLACK AND DAVIS' "PRACTICAL PHYSICS FOR SECONDARY SCHOOLS"

BY

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INTRODUCTION

It is now more than twenty years since we began to teach elementary physics in the laboratory and we already have many laboratory manuals. Why add another to the list? Every teacher of physics undoubtedly takes up the task of organizing his laboratory with great enthusiasm and high hopes. But sooner or later he finds that this business of teaching young people physics by means of laboratory exercises is a very difficult problem. No amount of costly apparatus or elaborate laboratory directions will produce that mental activity about physical phenomena that we all want to stimulate in our students.

Doubtless the ideal method would be for each teacher to make his own laboratory manual, and many have done so. This book is the result of one teacher's attempt to get together a set of experiments that represent a well-balanced course. The aim has been to make the directions so clear and concise that the average boy or girl, who already has in mind a general outline of the problem, can not only do the experiment but can also see the point to it. It is assumed that when the class assembles for the laboratory exercise the teacher will first make a few introductory remarks to indicate just what the problem of the day is and how it is related to the previous work and to the practical affairs of life; then he will briefly outline just how the problem is to be attacked in the laboratory. If the student has already mastered the written directions, he ought then to be able to proceed intelligently and expeditiously with the work in hand.

One reason why so much of our laboratory work in elementary physics is ineffective seems to be that the students get lost in the multitude of details and forget the point or purpose of the experiment. Sometimes the directions are given with such minuteness that the work is purely mechanical. This is reflected in the notebooks, which show no individuality and seem to indicate that the work has consisted merely in filling in certain blank spaces in a tabular form. It is, of course, expected that at first the student will need much help in arranging his notes in an orderly way, but these suggestions should be made less and less necessary as time goes on. The great danger in notebook work is artificiality. The student should write down in his own words such notes that when he reviews his work six months or a year later they will recall to his mind just what he did and what were his results.

In the early days of student laboratory work a very large fraction of the time devoted to physics was spent in the laboratory, but in recent years we have come to believe that most subjects can be presented in their *qualitative* aspects best by the teacher in clean-cut lecture-table demonstrations, while the work of the student in the laboratory should be to perform a few well-selected experiments involving simple measurements. It is, of course, always to be remembered that this elementary work is not primarily physical *measurements*, but *physics*. Therefore it is hardly worth while at this stage of the work to spend much time in discussing percentage errors which are to be reckoned in tenths of one per cent. The engineer often has to be satisfied with results which check within 5%. Why should we seek for such a high degree of accuracy as can only be attained by complicating the apparatus and the manipulation?

So it has come about that the suggested apparatus is very

simple and often crude. It is also suggested that the student do on an average only about one experiment per week. Frequent quizzes and reviews of the laboratory work have been found of great value. In this connection it is urged that the colleges provide for a *practical laboratory examination* as a part of the admission examination in physics, and that the schools use such practical examinations as a part of the routine work to test the student's achievements in physics. This laboratory examination should not be simply a repetition of experiments already performed, but should also to some extent test the student's originality and power to apply the methods of the laboratory to new problems.

In his search for the best experiments, each teacher gathers ideas from so many sources that he hardly knows to whom he is indebted for the result. In this case, the author owes a great deal to his fellow members of the Eastern Association of Physics Teachers, whose meetings have been so fruitful and suggestive. American teachers of elementary laboratory physics are under great obligations to Professor E. H. Hall of Harvard University for his persistent pioneer work in this field, and the author is under special obligations to him as his teacher, adviser, and friend. Professor J. M. Jameson of Pratt Institute has given a practical or engineering aspect to several of the experiments (Nos. 17, 32, and 33) in mechanics and electricity. Finally, it is a great pleasure to acknowledge the help of Professor Hermann Hahn of Berlin, Germany, whose "Handbuch für Physikalische Schülerübungen" is a mine of suggestions and information about laboratory experiments in physics.

N. H. B.

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A LABORATORY MANUAL IN PHYSICS

EXPERIMENT 1

MEASUREMENT OF A RIGHT TRIANGLE AND A CIRCLE

What is the relation between the sides of a right triangle and also between the circumference and diameter of a circle?

Sheet of paper.	Cylinder or brass weight.
30 cm. rule.	Strip of thin paper.
Right triangle.	Pin.

1. **Right Triangle.** Draw with a sharp hard lead pencil a right triangle with no two of its sides equal and none less than 10 cm. Make the corners clean and sharp. Label the triangle (Fig. 1) ABC, where C is the right angle. Measure each of the three sides and record each length in centimeters and a decimal fraction of a centimeter. The millimeters are to be expressed as tenths of a centimeter (0.1 cm.), and the tenths of millimeters, which are to be *estimated*, are to be expressed as hundredths of a centimeter (0.01 cm.).

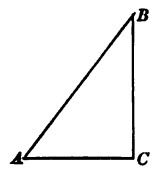


FIG. 1

Record the measurements as follows :

SIDES	LENGTHS
AB	——.—— cm.
BC	——.—— cm.
AC	——.—— cm.

To check these measurements, make the following computation :

$$\begin{aligned} (AB)^2 &= \cdots \\ (BC)^2 &= \cdots \\ (AC)^2 &= \cdots \\ \hline (AC)^2+(BC)^2 &= \cdots \end{aligned}$$

Compare $(AB)^2$ and $(AC)^2+(BC)^2$.

From a well-known proposition in Geometry, we know that *in any right triangle the square of the hypothenuse is equal to the sum of the squares on the sides.*

So if the arithmetical computation has been done correctly, the difference between $(AB)^2$ and $(AC)^2+(BC)^2$ must be due to the errors in measurement. Since the measurement of each side is bound to be in doubt as to the hundredths of a centimeter (0.01 cm.), the square of each side can have no more than four **significant** * figures, and no more should be recorded.

2. Circle. Measure the diameter across the circular face of a cylinder. Wrap tightly around the cylinder a thin strip of paper and prick a hole with a pin through the paper where it overlaps. Measure the distance between these pin-holes and record thus:

Circumference = — —. — — cm.
Diameter = — —. — — cm.

Compute the value of

$$\pi = \frac{\text{circumference}}{\text{diameter}} = —.— — \qquad \text{(By experiment.)}$$

True value of π = 3.14 (By Geometry.)

Error = ...

*Note. Since in each of the above measurements the tenths of a millimeter had to be estimated, it follows that each measurement is uncertain to at least 0.01 cm. For example, suppose one side of the triangle measured 12.46 cm.; it would mean that we were certain of the first three digits 12.4, but that the 6 was *doubtful* and probably somewhat in error.

Then it obviously follows that the square of 12.46 will also be somewhat in error. Let us see how much.

$$\begin{array}{r} 12.4\mathbf{6} \\ \underline{12.4\mathbf{6}} \\ \mathbf{7476} \\ 498\mathbf{4} \\ 249\mathbf{2} \\ \underline{124\mathbf{6}} \\ 155.\mathbf{2516} \end{array}$$

Problems. (1) A room is 3.55 meters high, 7.00 meters long, and 4.50 meters wide. Find the length of its diagonal to three significant figures.

(2) A cow is fastened to a stake by a rope 20 feet long. Find the perimeter of the circle she can graze over, expressed in feet and inches.

In the above computation, the doubtful digits are printed in black, and it will be seen that in the product we would retain only 155.**3**, saving only one doubtful figure. The last figure saved would be written 3 instead of 2, because what was thrown away was more than one-half.

As a general rule, in multiplying two numbers together, retain in the product only as many significant figures as there are in the least accurate factor.

In the same way, when we divide two numbers, which are obtained from measurements and so are more or less inaccurate, we keep in the result only one doubtful figure. Thus, suppose the diameter of a circle measured 5.25 cm. and the circumference 16.45 cm., then the quotient 3.1**3** has only three significant figures and the last **3** is somewhat uncertain.

```
5.25| 16.45 |3.13
      15 75
         700
         525
        1750
        1575
         175
```

In general, then, all numbers obtained from measurement are more or less inaccurate, and we may retain as significant digits only one doubtful digit. The result of an arithmetical computation can never be more accurate than its least accurate factor.

EXPERIMENT 2

DENSITY OF A BLOCK OF WOOD

How many grams does one cubic centimeter of wood weigh?

Rectangular blocks, such as maple, oak, pine, mahogany.
30 cm. rule.
Platform balance.
Set of weights.

To get the density of wood, *i.e.* the weight per unit volume, it is necessary to get the weight and the volume of a sample block.

First adjust the balance so that it will just balance evenly with no load in either scale pan. Then place the block of wood on the pan at the zero (left) end of the scale beam and counterbalance with weights. Steady the scale pans with the left hand while adding or removing the larger weights and so avoid jarring the balance and dulling the knife-edges. It will save time to begin by selecting a weight which is probably a bit too heavy, and if so, take it off and replace it with the next smaller weight. Continue in this way until you have the largest weight which is lighter than the object. Add then the next smaller weight to the scale pan and so on until within 10 grams of the weight. To make the final adjustment use the slider. Take great care in counting up the weights used, and record this at once in the notebook as the weight of the block.

The block of wood, although nearly rectangular, is not geometrically perfect, and therefore it is well to make several measurements of the length, width, and thickness. Then compute the average or mean length, width, and thickness, and so from these values the volume of the block. Finally, knowing the weight in grams of a certain number of cubic

centimeters of wood, we can easily compute *the weight of one cubic centimeter*, *i.e.* **the density of the wood.**

To measure the block to 0.01 cm. with an ordinary meter stick, requires, however, considerable care. The block should be laid on a sheet of white paper in good light and the measuring stick should be placed upon it so that one end of the block is exactly in line with some *centimeter* mark, such as the 10 cm. mark, as shown in Fig. 2. The other end of the block will probably not lie exactly in line with any millimeter mark on the scale and so it is necessary to estimate the fraction of millimeter. Express the result as centimeters and as a decimal fraction thereof, for example, 12.35 cm. To get the length, measure each of the four edges parallel to the grain of the wood, *a*, *b*, *c*, and *d* in Fig. 3. It is not at all likely that each of these measurements, if carefully made, will give exactly the same result to 0.01 cm. In finding the average of four such measurements, it is customary to *retain but one doubtful figure* and if the *second* doubtful figure be 5 or more, then add one to the *first* doubtful figure. Thus:

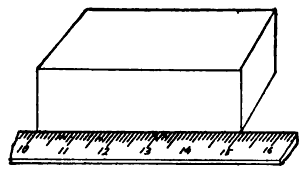


FIG. 2

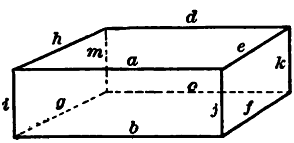


FIG. 3

	LENGTH	
a.	12.3**5** cm.	
b.	12.3**7** cm.	
c.	12.3**3** cm.	
d.	12.3**8** cm.	
4)	49.43 cm.	
	12.3**57** cm.	Average Length 12.3**6** cm.

To get the average width, measure each of the four long edges cross-wise the grain, *e*, *f*, *g*, and *h*. In a similar man-

ner measure the length of each of the four short edges, *i*, *j*, *k*, and *m*, and call the average of these four measurements the thickness of the block.

In computing the volume of the block, time will be saved if only significant figures are retained, that is, if only the first doubtful figure is kept. It should also be remembered that the result can be no more accurate than its least accurate factor, which is here the shortest side.

It is very desirable to record all measurements and results in an orderly way and so the following is suggested:

Weight of block No. - - - - = ... g.

Length		Width		Thickness	
a. - - - - - - -	cm.	*e.* - - - - - - -	cm.	*i.* - - - - - - -	cm.
b. - - - - - - -	cm.	*f.* - - - - - - -	cm.	*j.* - - - - - - -	cm.
c. - - - - - - -	cm.	*g.* - - - - - - -	cm.	*k.* - - - - - - -	cm.
d. - - - - - - -	cm.	*h.* - - - - - - -	cm.	*m.* - - - - - - -	cm.
4) - - - - - - -		4) - - - - - - -		4) - - - - - - -	
Average - - - -	cm.	Average - - - -	cm.	Average - - - -	cm.

Volume of block . . . . cm.^{3}

Density of . . . . . . wood . . . . g./cm.^{3}

Problem. If the density of aluminum is 2.6 g./cm.^{3}, how many grams does an aluminum rod 20.0 cm. long and 1.00 cm. in diameter weigh?

EXPERIMENT 3

THE STRAIGHT LEVER

How must the weights on a straight lever be arranged in order to balance?

Meter stick.
Fulcrum or support for meter stick.
Set of weights.
Thread.

Suspend or support a meter stick at its mid-point, and if it does not quite balance, place on the lighter side a piece of bent copper wire at such a point as to produce equilibrium. Hang a 200-gram weight at a distance of 20 centimeters to the right of the fulcrum, and then hang a 100-gram weight at some point on the other side so as to produce equilibrium. Record these weights as W_1 and W_2 and their distances from the fulcrum as d_1 and d_2 (Fig. 4).

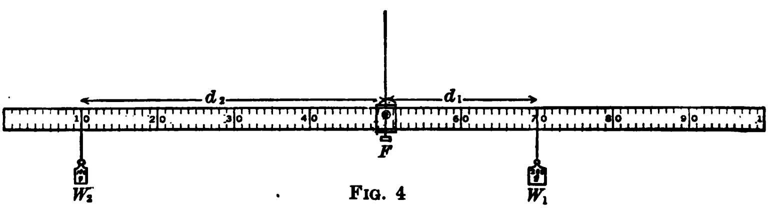


FIG. 4

The turning effect or **moment** of a weight depends on the amount of the **weight** and its **distance** from the fulcrum. Thus

Moment = weight × distance.

Calculate the moment of each of these weights about the fulcrum (F).

Repeat, using a different set of weights and calculate the moment of each weight about the fulcrum. Compare these two products.

Then hang two weights at different points on the same side of the fulcrum and balance them with a single weight on the other side. Compute the sum of the moments on one side of the fulcrum and compare this sum with the moment on the other side.

Finally suspend any convenient object, like a jackknife, screw driver, or monkey wrench, whose weight is not known, on one side of the lever and balance it with a known weight on the other side. Compute the weight of the object by the **principle of moments** which has just been illustrated. To check this result, weigh the object on the ordinary scales and compare the results.

Arrange these data and results in some convenient tabular form.

(*a*) *What relation seems to exist between the moment of the weight on the right and that on the left of the fulcrum?*

(*b*) *How does the sum of the moments on the right of the fulcrum compare with the sum of those on the left?*

(*c*) *Why does the weight of an object obtained by the meter-stick lever not agree exactly with that got on the scales?*

Problem. A seesaw plank is set in an east and west direction. A boy weighing 100 lb. is placed 6 ft. west of the fulcrum; a girl weighing 60 lb. is placed 6 ft. east of the fulcrum. Where must a second girl weighing 80 lb. be placed to balance the plank?

EXPERIMENT 4

WEIGHT OF A LEVER AND ITS CENTER OF GRAVITY

Where may the weight of a lever be considered to act?

Meter stick loaded at one end. Set of weights.
Triangular block of wood. Thread.

The loaded meter stick AL. (Fig. 5) may be considered an example of a non-uniform lever whose weight cannot be neglected. Hang a known weight W at some fixed point B, and then slide the meter stick along the triangular block of wood until the whole thing just balances. Call the fulcrum F, and note AF, the distance of the fulcrum from the end of the meter stick. The distance BF is the lever arm of the weight W, and the moment of W about F is equal to $W \times BF$.

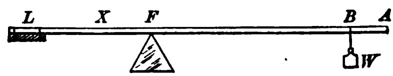


FIG. 5

It is evident that part of the weight of the lever tends to turn the lever down on the right side and that the rest of the weight of the lever tends to turn it down on the left side. It would often be very convenient, in dealing with actual levers, if we could find a point where we could consider the whole weight as concentrated, that is, as if the lever weighed nothing and as if we had another weight applied at this point. Let us call such a point, if there be one, X, and its distance from the fulcrum FX; then its moment is equal to the *weight of the lever* times FX. But this moment is equal to the moment on the other side $W \times BF$. In other words we have

$$\textit{Wt. of lever} \times FX = W \times BF,$$

and therefore

$$FX = \frac{W \times BF}{\textit{Wt. of lever}}.$$

Weigh the loaded meter stick and compute the value FX and so the position of X on the meter stick, *i.e.* the distance AX.

Repeat this experiment several times, using different known weights and at various positions, but each time computing AX.

Compare the various positions of X and of the center of gravity (CG) of the lever, which is found by balancing the lever alone without W.

What does this experiment show about where the weight of a lever may be considered to act?

It will be well to arrange the results in some such way as the following:

Weight of the loaded lever . . . . . . g.

W	AB	AF	BF	$BF \times W$	$FX = \dfrac{BF \times W}{\text{Wt. of Lever}}$	AX
100 g.	10.0 cm.					
200 g.	10.0 cm.					
200 g.	15.0 cm.					
500 g.						

Center of gravity (CG) is located . . . . . . cm. from A.

Problem. A boy who weighs 60 lb. uses as a seesaw a 15-ft. plank which weighs 70 lb. and which has its center of gravity in the middle. If he sits 1 ft. from one end, how far from this same end must the fulcrum be placed in order to balance?

EXPERIMENT 5

PARALLEL FORCES

What two conditions must always exist in order to have parallel forces in equilibrium?

4 spring balances (2000 g.).	Meter stick.
4 table clamps.	Stout cord (fishline).

Arrange the apparatus flat on the table as shown in the diagram (Fig. 6). Attach cords to the meter stick at vari-

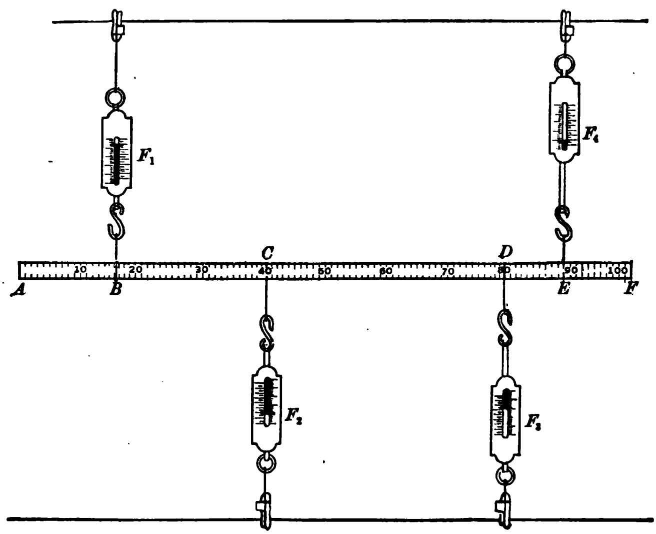


FIG. 6

ous points, fasten the spring balances to these cords, and arrange the table clamps so that the meter stick is about parallel to the edge of the table and so that all forces are parallel.

Tighten the cords attached to F_2 and F_3 until the balances indicate 1000 g. and 1500 g. respectively, and adjust F_1 and F_4 until the whole is in equilibrium. Then read and record the readings of F_1, F_2, F_3, and F_4 and the distances AB, AC, AD, and AE.

Repeat, using different values for F_3 and F_4, and finally repeat with different positions for C and D.

Compute in each case the sum of F_2 and F_3, and the sum of F_1 and F_4.

Compute the moment of each force about A and find in each case the sum of the moments tending to produce clockwise rotation and the sum of the moments tending to produce counterclockwise rotation.

Compute the moments in one case about F as a turning point. Compare the sum tending to produce clockwise rotation with the sum tending to produce counterclockwise rotation.

When several parallel forces are in equilibrium, (a) *how does the sum of the forces in one direction compare with the sum of those in the opposite direction;* (b) *how does the sum of the moments of the forces tending to produce clockwise rotation compare with the sum of the moments of the forces tending to produce counter clockwise rotation?*

Problem. If forces of 6 lb. north, 8 lb. south, 10 lb. north, and 15 lb. south are applied at distances 4, 8, 12, and 16 ft. respectively from the western end of the rod, what force must be applied to produce equilibrium and at what point and in what direction must it be applied?

EXPERIMENT 6

INCLINED PLANE

How does the effort required to pull a loaded car up an inclined plane depend on the grade?

Smooth board.	Spring balance.
Support for one end.	Set of weights.
Hall's car.	Meter stick.

Tip the board up at some convenient angle, such as 30°, and pull the car (*W*), which has been previously weighed, slowly up the incline (Fig. 7). The effort required to do

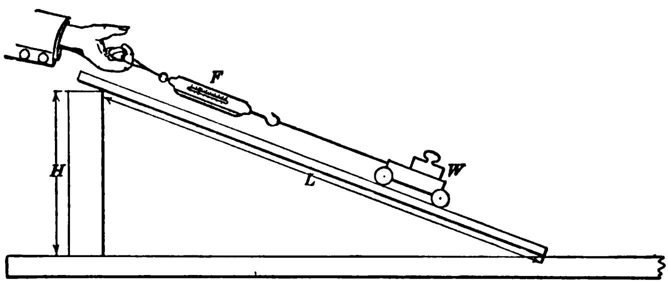


FIG. 7

this is a little more than would be required if friction could be entirely eliminated. But if the car is allowed slowly to roll down the incline, the effort required to hold it back will be slightly less because of the friction. Therefore take the mean or average of these two pulls, as the force (*F*) or effort which applied parallel to the incline would be needed to hold the car if there were no friction.

The **grade** of an incline is the ratio of the height to the length. For example, a 15 % grade means an incline which

rises 15 feet in going along the incline 100 feet. To compute the grade, then, measure some convenient height (H) and its corresponding length (L) along the incline. If, for example, we measure from the table top to the upper side of the inclined board, then we must also measure along the upper side of the board to the point where this surface cuts the table, and so it is usually more convenient to use the lower side of the inclined board in measuring *both* height and length.

Repeat this experiment with different loads in the car, and with the inclined plane at different grades in order to find some relation between the *effort* (F), the *total weight* (W) (*i.e.* car + load), and the *grade*. Compare $\frac{F}{W}$ and $\frac{H}{L}$.

Tabulate your data and results somewhat as follows:

W	F	H	L	$\frac{H}{L}$	$\frac{F}{W}$

Problem. What drawbar pull is necessary to pull a train weighing 350 tons up a grade of 15 ft. rise per mile of track, neglecting friction?

EXPERIMENT 7

SLIDING FRICTION

How does starting friction compare with sliding friction? How does sliding friction vary with pressure?

Friction board.	Set of weights.
Block of wood or friction box.	Spring balance.

The force needed to cause sliding varies much according to the materials, the condition of the bearing surface, lubrication, etc.

Place the board on the table and set the friction block or box upon it. Attach the spring balance to the block by a foot or two of cord (Fig. 8). By loading the block with weights we may get any desired pressure between the bearing surfaces. We may well start with as low a pressure as will give a fairly steady reading on the spring balance, and note carefully the force needed to start the loaded block and also the force required to keep it moving slowly at a uniform rate. Then increase the load and measure in the same way the friction at five or six other pressures.

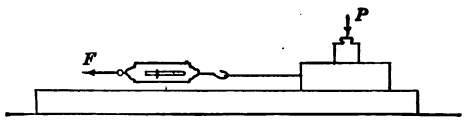


FIG. 8

The ratio between the force (F) required to cause sliding, and the perpendicular pressure (P) between the bearing surfaces, is called the **coefficient of friction.** Compute the coefficient of friction in each case as a decimal fraction.

Record the results in tabular form:

Trials	I	II	III	IV	V	VI
Weight of block						
Load						
Weight of block and load, *i.e.* pressure						
Starting friction						
Sliding friction						
Coefficient of friction						

How does the starting friction compare with the sliding friction?

Does the sliding friction increase with the pressure?

Does the coefficient of friction increase with the pressure?

Problem. If the coefficient of friction between two well-lubricated metal surfaces is 0.03, what force is needed to make 500 pounds slide?

EXPERIMENT 8

EFFICIENCY OF A COMMERCIAL BLOCK AND TACKLE

What fraction of the work put into a commercial block and tackle is got out under various conditions?

Two double pulleys (commercial).
Rope.
Weights.
Spring balance.
Meter stick.

Attach one block to a ring in the ceiling or to a suitable support from the wall, and apply various loads, such as 5, 10, 15, 20 lb., to the movable pulley and determine — using the spring balance (Fig. 9) — the effort (F) required to raise the load (W) slowly. Determine also the distance through which the effort must be exerted in order to lift the

weight 1 foot. Compare this distance with that which you would expect from the arrangement of ropes and pulleys.

Compute the **input** and **output** at the different loads for a hoist of 10 feet. The work "put in" is equal to the effort × effort distance, and the work "put out" of a machine is equal to resistance × resistance distance. Note that the output here means only the *useful output*, *i.e.* work done in lifting the load exclusive of the weight of the movable block.

Finally compute the **efficiency**, *i.e.* ratio of output to input, of the commercial block and tackle at the different loads. *Why is the efficiency not the same at different loads? What becomes of the "wasted work"?*

Plot a curve to show graphically the relation between *efficiency* (vertical distance to curve) and *load* (horizontal distance). *Explain the form of the curve.*

It will be convenient to record the data and results of this experiment in tabular form, somewhat as follows:

FIG. 9

Effort moves through . . . . ft. when weight is lifted 10 ft.

LOADS (lb.)	EFFORT (lb.)	OUTPUT PER 10 FT. LIFT (ft.-lb.)	INPUT (ft.-lb.)	EFFICIENCY = $\frac{\text{OUTPUT}}{\text{INPUT}}$ (%)

Problem. If the maximum pull which three men can exert is 400 lb., and if a 1000-lb. piano is to be lifted by a block and tackle whose efficiency is assumed to be 65%, what is the least number of sheaves which can be used in each block? Draw a diagram.

EXPERIMENT 9

PRINCIPLE OF ARCHIMEDES

I. *How much does a body seem to lose in weight when entirely immersed in a liquid?*

II. *How much liquid does a floating body displace?*

Overflow can.
Platform balance with weights and support, or spring balance.
Solids (denser than water), 100–250 g., such as stone, coal, glass, etc.
Solids (less dense than water) such as blocks of wood, apples, etc.
Beaker or tumbler.
Battery jar.
Thread.

I. **Solids that Sink.** By weighing a solid, such as a piece of stone, in air and then when entirely immersed in water, the loss in apparent weight can be computed. This loss of weight evidently depends on the size of the stone and so on the weight of the liquid displaced.

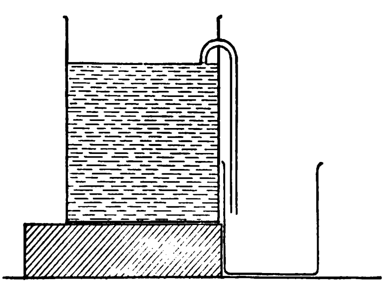


FIG. 10

To determine this weight of the liquid displaced, a can with a spout, called an overflow can (Fig. 10), is filled until water runs out of the spout. Then by placing a weighed glass beaker under the spout and care-

fully lowering the piece of rock into the overflow can, the water which is displaced overflows into the beaker and may be caught and weighed.

Record these observations and results as follows:

Weight of solid in air	g.
Weight of solid in water	g.
Loss of weight of solid in water	g.
Weight of catch glass, empty	g.
Weight of catch glass and water displaced	g.
Weight of water displaced	g.

Compare the weight of the displaced water with the loss of weight of the stone in water.

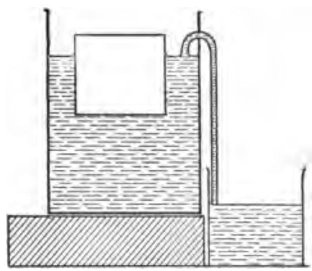


FIG. 11

II. **Solids that Float.** To find out how the weight of a floating body compares with the weight of liquid displaced by it, first weigh the object, such as an apple or block of wood, and then arrange the overflow can and beaker as in Fig. 11, and determine the weight of water displaced by the floating object.

The observations to be obtained are as follows:

Weight of solid	g.
Weight of catch glass, empty	g.
Weight of catch glass and water displaced	g.
Weight of water displaced	g.

Compare the weight of a floating object with the weight of the liquid displaced by it.

Problem. A metal bar, 10 cm. long, 2 cm. wide and 1.5 cm. thick, weighs 200 g. in water. How much does it weigh out of water?

EXPERIMENT 10

SPECIFIC GRAVITY OF A SOLID

How many times as heavy as an equal volume of water is a solid which sinks in water?

Solids (such as porcelain, solid glass stopper, pieces of metal, stones, sulphur, etc.), weighing 100–250 g.

Thread.

Platform balance with weights and support, or spring balance.

Battery jar.

To get the weight of a piece of porcelain, glass, or metal, we have merely to weigh it in the usual way. To get the weight of an equal bulk of water, we make use of Archimedes' principle; namely, that the *weight of an equal bulk of water is equal to the loss of weight when immersed in water.* The **specific gravity** of a solid is the ratio of the weight of the solid to that of an equal volume of water.

Record the observations and results in tabular form:

	Glass	Marble	
Weight of solid in air			
Weight of solid in water			
Loss of weight in water			
Weight of equal volume water			
Specific gravity of solid			

Problem. A brass cylinder (sp. gr. 8.4) weighs 168 g. in air. How much will it weigh in water?

EXPERIMENT 11

SPECIFIC GRAVITY OF A SOLID LIGHTER THAN WATER

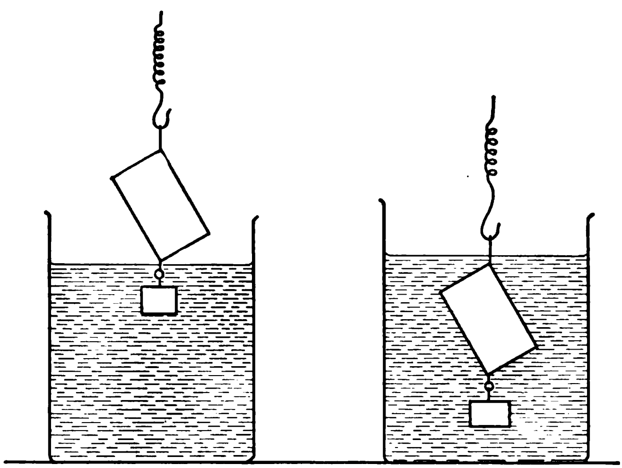
How many times as heavy as an equal volume of water is a solid which floats in water?

Block of wood or paraffine.
Spring balance, or platform scales with weights and support.
Jar of water.
30 cm. rule.
Thread.
Lead sinker.
Wooden cylinder.
Support for cylinder.

I. **Sinker Method.** Just as in experiment 10, it is necessary to determine the weight of the solid and the weight of an equal volume of water.

Weigh the block of wood in air.

To get the weight of an equal volume of water, since the object may be irregular and is lighter than water, attach a sinker large enough to submerge the body. The lifting



(a) Fig. 12 (b)

effect of the water on the block is due to the weight of the water displaced by the block.

To get this lifting effect of the water on the block, get the weight of the block in air with the sinker attached and under water (Fig. 12 *a*). (It may be more convenient to weigh the sinker under water and add this to the weight of the block in air.) Then weigh *both* block and sinker submerged (Fig. 12 *b*) and by subtraction get the lifting effect of the water on the block, *i.e.* weight of equal volume of water.

Arrange the data and results as follows:

Weight of block	g.
Weight of sinker in water	g.
Weight of block in air and sinker in water . .	g.
Weight of block and sinker both in water	g.
Lifting effect of water on block	g.

$$\text{Specific gravity of block} = \frac{\text{Weight of block in air}}{\text{Lifting effect of water on block}} =$$

II. **Flotation Method.** When the object is of regular form, its specific gravity can often be easily determined by finding the fractional part of the whole volume which is submerged, inasmuch as the volume submerged represents the weight of the block and the whole volume the weight of an equal volume of water.

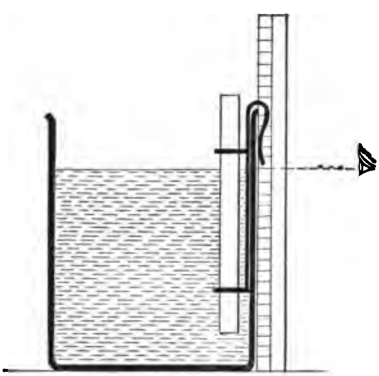


FIG. 13

To illustrate this method, use a cylinder of wood and float it endwise in water (Fig. 13). Then the specific gravity is equal to length submerged divided by the whole length.

Record the data and results as follows: —

Length of stick under water . . . . cm.
Whole length of stick . . . . cm.

$$\text{Specific gravity} = \frac{\text{Length of stick submerged}}{\text{Whole length of stick}} = \quad . \ . \ .$$

Problems. (1) A cork (sp. gr. 0.25), which weighs 50 g. alone in air, is fastened to a sinker that weighs 200 g. alone in water. How much will both together weigh in water?

(2) A block of wood, 20 cm. × 15 cm. × 10 cm., floats in water. If its sp. gr. is 0.7, how many cubic centimeters are above water? Which edge floats upright and how many centimeters of it are above the water?

EXPERIMENT 12

SPECIFIC GRAVITY OF A LIQUID

How many times as heavy as water is gasolene?

Platform balance, weights and support, or spring balance.	Jar of gasolene or other liquid.
Glass-stoppered bottle.	Piece of glass or porcelain.
Jar of water.	Thread.
	Cloth.

liquid
water

I. **Bottle Method.** If we know the weight of an empty bottle and stopper, and then determine the weight of the bottle full of gasolene (or any liquid) and also the weight of the same bottle full of water, by subtraction we can get the weight of a certain volume of the liquid and also of the same volume of water. Then by division we get the specific gravity of the liquid.

It is necessary, of course, to wipe the outside of the bottle dry each time and to be sure that there are no air bubbles

left in the bottle, *i.e.* that the bottle is quite full in each case.

Record the weighings in tabular form:

Weight of empty bottle with stopper	g.
Weight of bottle full of liquid (gasolene)	g.
Weight of bottle full of water	g.
Weight of liquid in bottle	g.
Weight of water in bottle	g.
Specific gravity of liquid	

II. **Displacement Method.** If we weigh some object, like a glass stopper, in air and then in a liquid like gasolene, the loss of weight is equal, according to the Principle of Archimedes, to the weight of the liquid displaced. In the same way, by weighing the same object in water, the loss of weight gives the weight of an equal volume of water. By comparing these *losses* in weight in the liquid and in water, we can determine the specific gravity of the liquid.

Record the weighings as follows:

Weight of glass stopper in air	g.
Weight of glass stopper in liquid	g.
Weight of glass stopper in water	g.
Loss of weight in liquid	g.
Loss of weight in water	g.
Specific gravity of liquid	

Problems. (1) A sp. gr. bottle weighs 5.25 g. empty and, when full, holds just 50 g. of water. How much will it weigh when filled with mercury (sp. gr. 13.6)?

(2) A glass cylinder weighs 100 g. in air and 60 g. in water. What will it weigh in concentrated sulphuric acid (sp. gr. 1.84)?

EXPERIMENT 13

BOYLE'S LAW

How does the volume of a given quantity of gas kept at constant temperature vary with the pressure?

Boyle's Law apparatus either with two adjustable tubes connected by rubber tubing, or with a glass J-tube mounted on some convenient upright frame.

Mercury.

Millimeter cross-section paper.

The closed tube (*B*, Fig. 14) contains a column of air which is imprisoned by the mercury column. The volume of this air is diminished or increased by changing the pressure upon it; and its volume is determined either directly in cubic centimeters from the graduations on the closed tube or by measuring the length of the air column, assuming that the bore of the tube is uniform.

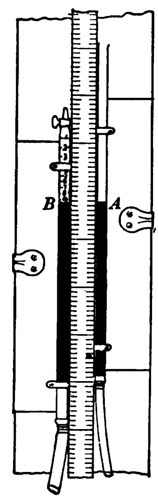


FIG. 14

The pressure exerted on this column of air, when the mercury stands at the same level in the two tubes, is evidently the atmospheric pressure. This is obtained by reading the barometer and is usually expressed as a certain number of centimeters of mercury. When, however, the mercury in the open tube (*A*) stands at a lower level than that in the closed tube (*B*), then the air in the tube is under less than atmospheric pressure, and the pressure is equal to the barometer pressure (centimeters of mercury) *minus* the difference in level, also expressed as centimeters. But when the level of mercury in the open

tube is higher than it is in the closed tube, then the air is under more than atmospheric pressure and the pressure is equal to the barometric pressure *plus* the difference in levels. By merely shifting the relative positions of the two tubes (or in the J-form of apparatus by pouring in more mercury), it is possible to vary the pressure on the enclosed air from considerably below that of one atmosphere to nearly two atmospheres and to observe the resulting changes in the volume of the air in the tube.

Since the volume of a gas is very sensitive to changes in temperature, it is well not to handle the air column. In reading the position of the mercury on the scale, take the top of the mercury each time, as in reading the barometer. Start with the least pressure that your apparatus will give and gradually increase by at least six steps to the maximum.

Record your readings and results in tabular form somewhat as follows, keeping only the significant figures:

Atmospheric pressure (Barometer) . . . . cm.

V Volume of Air	Height of Mercury in Closed Tube (B)	Height of Mercury in Open Tube (A)	Difference in Levels	P Pressure	$V \times P$
. . . $cm.^3$	. . . cm.	. . . cm.	. . cm.	. . cm.	. . .

From this experiment it will be clear that when the *pressure increases*, the *volume decreases*. Since, moreover, in the several trials, the product of volume times pressure is nearly constant, *i.e.* $V \times P = V' \times P' = V'' \times P''$, it follows that the volume of the air in the tube varies *inversely* as the pressure. In other words when the pressure is doubled, the volume is halved.

This relation should also be shown by plotting a curve on cross-section paper, using the observed pressures as vertical distances and the volumes as horizontal distances.

Problem. In a certain experiment of this sort, the data showed that the volume of air was 25.5 cm.^{3} when the pressure was 85.5 cm. What would have been the volume when the pressure was 20 lb. per sq. in.?

14.7 : 76 :: 20 : x   25.5 : 85.5 = 103 : x

EXPERIMENT 14

DENSITY OF AIR

What does a liter of air weigh under the conditions of temperature and pressure of the room?

Two-liter round bottom flask, with rubber stopper and connections.
Air pump.
Mercury gauge.
Screw pinchcock.
Equal-arm balance sensitive to 0.01 g.
Set of weights.
Barometer.

First of all, it is assumed that the volume of the flask has been determined by filling it with water and then measuring the volume of water with a graduate. When this volume has once been determined, it is marked on the flask and this part of the experiment need not be repeated; but great care should be taken to have the flask dry and clean inside and out before attempting to weigh its content of air.

Connect the flask, mercury gauge, and air pump as indicated in the diagram (Fig. 15). After pumping out some of the air, pinch the rubber tube connected with the pump and watch the mercury gauge to see whether there is a leak in the connections. A gradual drop of the mercury would

indicate such a leak, which must be stopped before proceeding. When all the connections are tight, continue pumping for at least five minutes and then read the mercury gauge (*i.e.* height of mercury in tube above that in glass). Close the pinchcock (*P*) near the bottle tight.

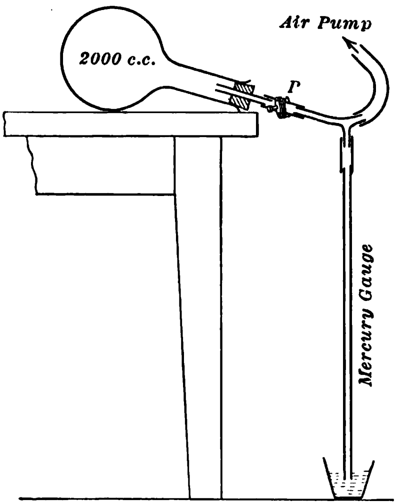


FIG. 15

Disconnect the flask with its tube and pinchcock, suspend it from one arm of the balance, and counterpoise its weight with great care. Without disturbing the flask or balance, open the pinchcock and let the air in. Add the necessary weights to make up for the air admitted. This added weight represents the weight of air admitted to the flask. But not quite all the air was removed from the flask by the pump. In fact, only that fraction of total volume of the flask indicated by the height of mercury in the pressure gauge divided by the height of mercury in the barometer, was removed.

Having calculated, then, the number of cubic centimeters of air admitted and its weight, we may readily compute the weight of 1000 cm.^{3}.

Since the weight of air varies greatly with the temperature and pressure, it is well to record the room temperature and barometric pressure and then check the experimental result of this rather crude method with the results given in the tables in the Appendix.

Arrange the data and calculated results in an orderly fashion and draw a diagram of the apparatus.

Problem. If one cubic foot of air weighs about 1.3 ounces, how many pounds of air are contained in a schoolroom which is 40 feet × 30 feet × 12 feet? 1170 lbs.

EXPERIMENT 15

SPECIFIC GRAVITY OF A LIQUID BY BALANCING COLUMNS

How many times as heavy as water is a saturated solution of blue vitriol as indicated by the heights to which the atmospheric pressure will raise columns of these liquids?

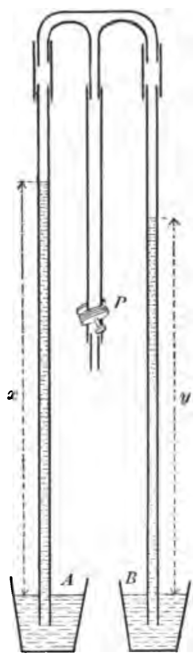


FIG. 16

Two glass tubes about 80 cm. long.
Glass T-tube with rubber connections.
Screw pinchcock.
Tumbler of water.
Tumbler of solution of blue vitriol ($CuSO_4$).
Meter stick.

Support the T-tube (Fig. 16) at such a height that the ends of the glass tubes will nearly reach the bottoms of the tumblers. Suck out some of the air from the tubes until the water rises about 60 cm. and then close the screw pinchcock (*P*). Observe carefully the levels of the liquids to see if the apparatus is leaking, as will be shown by a gradual drop of the liquids in the tubes.

It is evident that the pressure of the air on the liquids in the tumblers is holding

up the two columns, and the pressure is just balanced by pressure of the liquid in the tubes plus the air above. That is, each liquid column exerts the same pressure at its base. It is also evident that this pressure depends on the height and density of the liquid, so the liquid of less density will have the greater height; in other words, the densities of the two liquids (*A* and *B*) vary inversely as the heights of the columns (*x* and *y*). So that

$$\text{Specific gravity of blue vitriol solution} = \frac{\text{Density of blue vitriol}}{\text{Density of water}}$$

$$= \frac{\text{Height of water column}}{\text{Height of blue vitriol column}}$$

To obtain these heights we shall need to make the following measurements and computations:

	Trials		
	#1	#2	#3
Height of water column above the table			
Height of water in tumbler above the table			
Net height of water column raised *			
Height of blue vitriol column above the table			
Height of blue vitriol in tumbler above the table			
Net height of blue vitriol raised *			
Specific gravity of blue vitriol			

* Note. Subtract from the height of each column, as measured, the height to which it was raised by capillary action at the beginning.

Problem. How high would a glycerine barometer (such as is in the South Kensington Museum, London) stand, when the mercury barometer reads 30 inches? Sp. gr. of glycerine = 1.26. Sp. gr. of mercury = 13.6.

EXPERIMENT 16

PARALLELOGRAM OF FORCES

When three non-parallel forces are acting on a body, what must be their relative directions and magnitudes in order to produce equilibrium?

Three spring balances.
Three clamps.
30 cm. ruler.
Fishline.
Block of wood.

To the middle of a piece of fishline about 40 cm. long tie a second piece about half as long. At each of the free ends make a loop and attach the hook of a spring balance. To the ring of each balance attach a strong string, and then arrange the clamps, balances, and strings as shown in Fig. 17.

Pull each balance until its index is about in the middle of

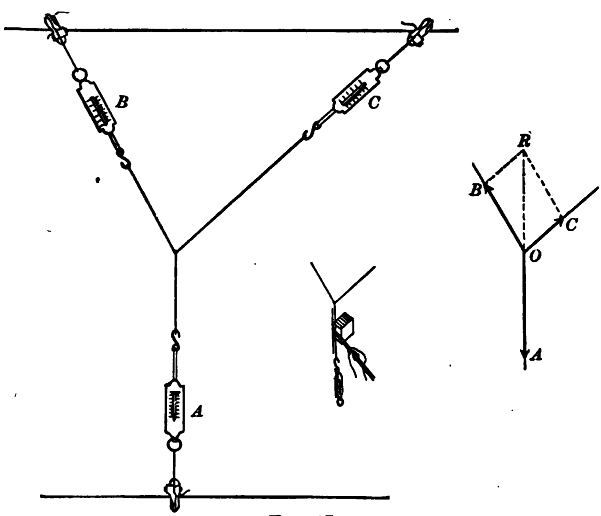


FIG. 17

the scale where it is most reliable, and then slip a page of the notebook under the cord connecting the balances, so that the knot comes about in the middle of the page.

In order to show the direction of each cord on the paper, place a rectangular block alongside and draw a line directly under each cord. Record on each line the pull indicated by the balance, and then relieve the tension on the spring balances. Observe the zero reading of each balance and apply the proper correction to the reading just recorded. If the zero reading is less than zero, add the correction to the balance reading recorded on the paper; if it is more than zero, subtract the proper amount.

If the experiment has been carefully done, the three lines representing the three forces will, when prolonged, intersect at a common point. Measure off on each line a distance corresponding to the force, according to any convenient scale, such as 200 g. to 1 cm. Make an arrowhead at the end of each measured line and erase that part of each line which lies beyond the arrowhead.

On any two of these lines construct a parallelogram, using a ruler and compass to get the lines exactly parallel. Draw the three original force lines as solid lines (*OA*, *OB*, and *OC*) and the lines needed to complete the parallelogram (*BR* and *CR*) and the diagonal (*OR*) as broken or dotted lines. Draw the diagonal of this parallelogram from the central point, measure its length, and compute the magnitude of the force which it represents. For example, a line 15.6 cm. long represents a force of 3120 g. when the scale is 200 g. to 1 cm. This diagonal line represents the **resultant** of the two forces which form the sides of the parallelogram.

How does the resultant of two forces compare with the third force (a) *in magnitude and* (b) *in direction?*

Problem. Find the direction and magnitude of a force needed to balance the effect of 12 lb. acting north and 16 lb., east.

EXPERIMENT 17

FORCES ACTING ON A SIMPLE TRUSS

How much is the thrust exerted by a simple stick when used with a "tie" to support a weight?

Stick with foot support (Pratt Inst. model).
Two spring balances.
Scale pan and weights.
Large protractor.

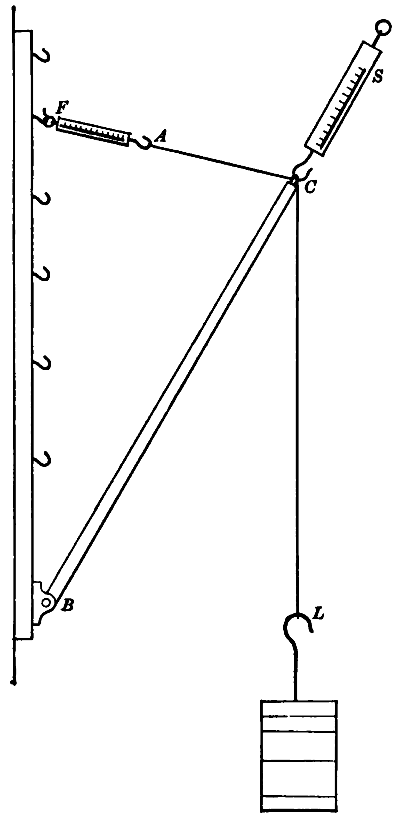


FIG. 18

Set up the apparatus as shown in Fig. 18, so that the stick *BC* is not horizontal. Add enough weights at *L* to stretch the balance *F* nearly to its full scale reading. The weight of the stick itself may be neglected because it is so small in comparison with the other forces.

Measure with a large protractor the angles *BCL* and *ACL* and record the weight at *L*.

To find the tension in

AC, draw a careful diagram of the three forces with the force *CL* to some convenient scale. Compare the result of this computation with the reading of the balance *F*.

Also by the same diagram, compute the compression on the stick *BC*. To test this, attach a second balance at *C* and pull out in the line of the stick *BC* until the end of the stick at *B* just leaves the wall. Compare this pull (*S*) with the computed compression in the stick *BC*.

Change the angle of the stick to the wall and repeat the experiment, making the necessary diagrams and taking check readings as before.

Record the readings also in tabular form as follows :

Case	L	$\angle BCL$	$\angle ACL$	F		S	
				Computed	Measured	Computed	Measured
I							
II							

Problem. If the stick *BC* is 10 ft. long and is placed at an angle of 45° to the wall, what is the tension in the tie *CA* which is horizontal when the load is 2 tons? What is the compression in the stick *BC*?

EXPERIMENT 18

BREAKING STRENGTH OF WIRE

How many kilograms of force are required to break No. 27 spring brass wire, steel wire, and copper wire?

Wire-breaking apparatus (Fig. 19).
10 kg. spring balance.
Micrometer.
Spools of steel, brass, and copper wire, # 27.

The apparatus (Fig. 19) is so designed that the tension on the wire at the instant it breaks, is recorded on a spring balance (*B*). The tension is applied by means of a crank

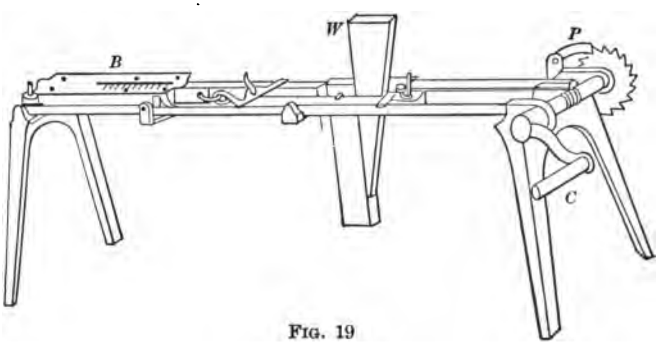


Fig. 19

(*C*) which turns an axle on which the wire is wound. The other end of the wire is attached to the spring balance by means of a frame. As this frame is pulled, a wedge (*W*) drops down which holds the index of the balance just where it was at the instant of breaking.

First slip one end of the wire through the hole in the crank shaft and bend the end over sharply so as to extend along the shaft. In this way one or two turns of the handle will cause the wire to wind over the end and so fasten it

securely. Pass the other end of the wire a couple of times around the wooden post on the sliding frame and clamp the end under the binding post. Let the wedge rest lightly in the slot of the sliding frame. Set the pawl (*P*) so that it will rest on the toothed wheel attached to the shaft and so prevent the shaft from turning backward.

Now turn the crank slowly and cause a slight tension in the wire. Measure with a micrometer the diameter of the wire in at least two places, and increase the tension on the wire by turning the crank and keeping the wedge down in the slot until the wire breaks. As the wedge fills the slot, it holds the spring balance at just the position it was in when the wire broke. Record this force in kilograms.

Repeat the experiment twice and find the average of the three readings for the breaking strength of # 27 brass wire. If time permits, try also steel wire and copper wire.

Problem. From the result of your experiment calculate the force in kilograms needed to break a wire of the same material 1 $mm.^2$ in cross section.

EXPERIMENT 19

BENDING OF RODS

How does the bending of a rod vary under different loads? How is the bending affected, (a) *if the rod is shortened to one half its original length,* (b) *if the rod is doubled in width,* (c) *if it is doubled in thickness?*

Rods of wood, steel, or brass 110 cm. × 1 cm. × 1 cm.	Indicator lever, or micrometer screw with cell and telephone receiver.
Rods of same material but 110 cm. × 2 cm. × 1 cm.	Vertical scale.
	Set of weights.
△ Supports.	Pan for weights.
Board to support apparatus.	Meter stick.

Place the board across the gap between two laboratory tables and set up the apparatus as shown in Fig. 20. Of course we should expect a rod to bend more with a heavy

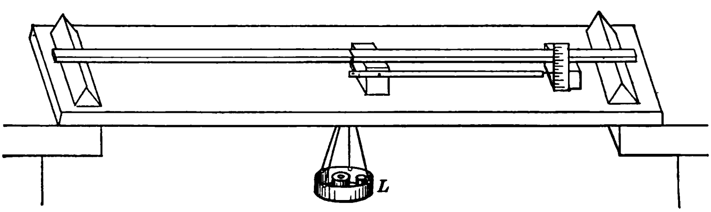


FIG. 20

load than under a light one, and so in this experiment we will try to show just how this bending varies with various loads (L). Since the rod gets a permanent "set" or bend, when loaded beyond a certain point, called the "elastic limit," we must each time remove the load and read the zero point. The amount of the deflection or bending which a rod will stand and still recover is very small, and so some special

method has to be adopted to measure this deflection, such as a magnifying lever (Fig. 20) or a micrometer screw (Fig. 21).

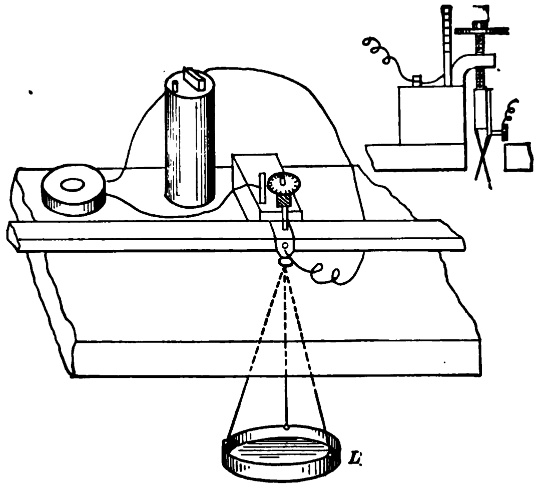


FIG. 21

Record the loads and deflections of the rod in tabular form somewhat as follows:

I. LENGTH BETWEEN SUPPORTS 100 CM. WIDTH 1.0 CM. THICKNESS 1.0 CM.

LOAD	INDICATOR READINGS		ACTUAL DEFLECTION	DEFLECTION PER 100 G.
	Before loading	After loading		
100 g.				
200 g.				
300 g.				
400 g.				
500 g.				

II *a*. Length between Supports 50 cm. Width 1.0 cm. Thickness 1.0 cm.

500 g. 1000 g.				

II *b*. Length between Supports 100 cm. Width 2.0 cm. Thickness 1.0 cm.

200 g. 400 g.				

II *c*. Length between Supports 100 cm. Width 1.00 cm. Thickness 2.0 cm.

500 g. 1000 g.				

From a comparison of the results shown in the last column under "Deflection per 100 g.," in case I, *state how the deflection varies with the load.*

By comparing the average deflection per 100 g. in cases I and II *a*, *state how the bending decreases when the length is halved.*

By comparing the average deflection per 100 g. in cases I and II *b*, *state how the bending decreases when the width is doubled.*

Finally by comparing the average deflection per 100 g. in cases I and II *c*, *state how the bending decreases when the depth is doubled.*

Note. If metal rods are used with a micrometer screw and heavier loads, which are needed, the results will be more consistent.

Problem. If a beam 10 ft. long, 4 in. wide, and 6 in. thick, is bent 0.5 in. under a load of 300 lb., how much load would it take to bend a beam 5 ft. long, 2 in. wide, and 3 in. thick, the same amount?

EXPERIMENT 20

ACCELERATED MOTION

How does the distance traversed by a moving body under constant acceleration vary with the time?

Grooved plank according to Duff.
Steel ball, 1.5″ diam.
Blocks to support one end of incline.
Meter stick.
Pepper box with lycopodium powder.
Cloth.

When the grooved plank (Fig. 22) is placed horizontally on the table, a steel ball placed on one edge will, when released, oscillate back and forth like a pendulum. Although

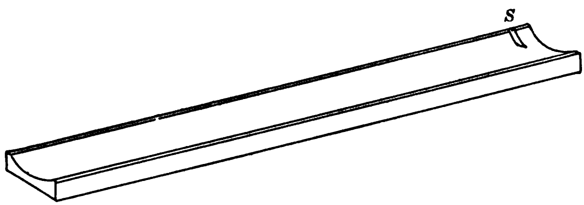


FIG. 22

the swings decrease in amplitude, yet the time of each swing remains constant. When the plank is tilted so that one end is higher than the other, a ball placed at the top in the middle of the groove will roll down, going faster and faster until it reaches the bottom.

In this experiment we shall combine this oscillatory motion back and forth across the groove with the accelerated motion down the incline in such a way as to make the oscillatory motion mark off equal intervals of time for the study of the accelerated motion.

First wipe off the trough with a damp cloth and rub it thoroughly dry, then sprinkle it with lycopodium powder.

Tilt the plank with blocks, taking care to keep the under edges at the upper and lower ends exactly horizontal. Place the ball at the top of the groove against the metal strip (S) which serves as a guide until it reaches the middle line. When the ball is released, it goes zigzagging down the groove. If the powder is blown off, we see distinctly the path traced on the blackboard, somewhat as shown in Fig. 23. We have now simply to measure certain distances along the midline to understand the relation of *distance* to *time* in a case of accelerated motion.

FIG. 23

In the second column we record the distances traversed in 1 interval of time, 2 intervals, 3, and so on, that is, AB, AC, AD, AE, etc.

In the third column we record the separate distances covered in the 1st interval of time, in the 2d interval, and so on, that is, AB, BC, CD, etc.

From a study of the result given in the fourth column $\left(\frac{s}{t^2}\right)$, *what relation seems to exist between the space, s, and the time, t?* From a study of the results in the last column $\left(\frac{d}{2t-1}\right)$, *what relation seems to exist between the separate distances (d) and the odd numbers given by the expression* $(2t-1)$?

Time Intervals (t)	Space Traversed (s)	Distance covered in Each Time Interval (d)	$\frac{s}{t^2}$	$\frac{d}{(2t-1)}$
1				
2				
3				
4				
5				

Problem. As the board is tilted more and more, the value $\frac{s}{t^2}$ increases, until when the board is vertical and the ball falls freely, $\frac{s}{t^2} = 16.1$, where t is expressed in seconds and s in feet. How far would a body fall freely in 3 seconds?

EXPERIMENT 21

THE FIXED POINTS OF A THERMOMETER

How to test the fixed points of a thermometer, i.e. 0° *and* 100° *C.*

How much is the boiling point of water affected by a change of 1 *centimeter in the barometric pressure?*

Steam boiler and Bunsen burner.	Small glass tumbler.
Mercury U-tube gauge.	Cracked ice (clean).
Thermometer (– 10° to 110° C.).	Screw pinchcock.

Fill the boiler about half full of water, screw the chimney or top down firmly, and attach the necessary gauge (Fig. 24). Open up the pinchcock (A) near the top of the chimney and start heating the water.

I. **Freezing Point.** Fill a glass tumbler with clean cracked ice and pour over it enough water to fill the spaces around the pieces of ice. Put the thermometer bulb down into the melting ice, so that you can just see the mercury. After a few minutes, when the mercury has ceased to fall and has come to a definite position, read the thermometer to one tenth of a degree, and record this as the *freezing point* of your thermometer. The error is the difference between this reading and zero.

II. **Boiling Point.** Carefully insert the thermometer in the stopper of the steam boiler, so that the 100° mark on

the scale projects just a little above the stopper. Let the steam flow around the bulb and stem for several minutes until the thermometer has come to a fixed reading, then read and record its position and also the barometer height.

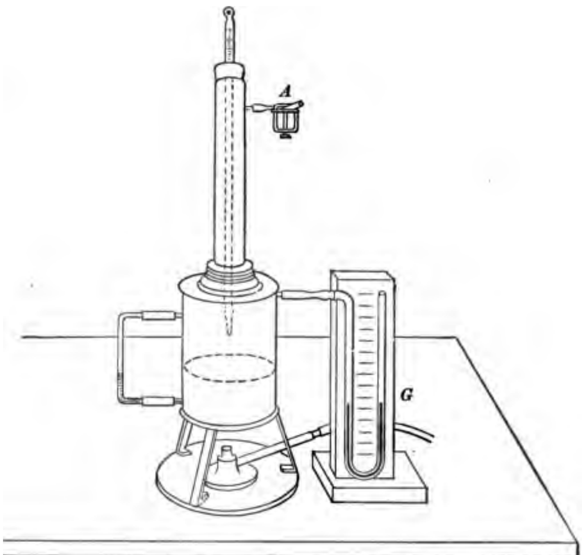


FIG. 24

III. **Pressure of Steam and its Temperature.** Since the boiling point of water is much affected by changes in pressure, it has been necessary to fix on some **standard barometric pressure**, and this is 760 mm. As the barometer is very seldom just at this point, it is necessary to know how to compute the true boiling point of water at any pressure. To do this we need to know the effect on the temperature of steam of a change in pressure of 1 cm.

When the steam is escaping freely into the air, the mercury in the gauge (*G*) reads the same in each arm. Now

gradually close the steam exit (A) by screwing up the pinchcock until the pressure gauge shows a difference in levels of about 6 or 8 cm. and has become fairly steady, then read the thermometer, and remove the burner.

How much has the temperature of the steam been raised by increasing the pressure?

How much is the temperature of steam raised per centimeter increase of pressure?

Very careful and repeated experiments of this sort have shown that the temperature of steam is changed about 0.37° for each centimeter of change of pressure. Compute, then, the true temperature of steam to-day and then the error in your thermometer.

Problem. A standard thermometer was found on a certain day to read in steam 98.5° C.; what was the pressure?

EXPERIMENT 22

LINEAR EXPANSION OF A SOLID

How much does one centimeter of aluminum expand when heated one degree Centigrade?

Linear expansion apparatus according to Hall or Cowen.
Boiler and burner.
Thermometer.
Barometer.
Meter stick.

Since the amount which a solid expands is exceedingly small, it is difficult to measure it with great precision. One of the many methods of measurement of this slight expansion makes use of a lever to magnify the actual expansion as shown in Fig. 25.* The metal tube is heated by passing

* This form of apparatus was designed by Mr. C. M. Hall of Springfield, Mass.

steam through it. One end of the tube is made fast with a pin (P), and the other end, as the rod expands, turns a bent lever (L) about a point (A). The expansion of the tube

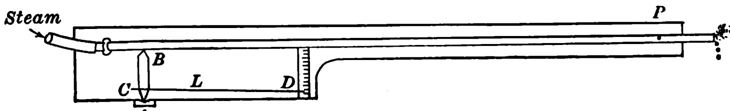


FIG. 25

is magnified as many times as the short arm (AB) of the lever is contained in the long arm (CD). Therefore to get the actual expansion we have only to divide the movement of the pointer by the magnifying power of the lever.

In another form of apparatus the expansion is measured by allowing the tube (T) to rest on a needle (N), which in turn rests on roller bearings (BB) as shown in Fig. 26.*

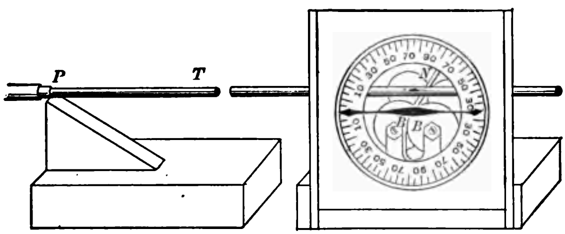


FIG. 26

The rotation of the needle is measured on a circular scale by a pointer. Evidently if the needle turns around once, the tube has expanded a distance equal to the circumference of the needle; and if it turns less than a complete revolution, the tube has expanded the corresponding fraction of the circumference of the needle.

* This form of apparatus was designed by Mr. G. A. Cowen of Jamaica Plain, Boston.

In the first method the short arm of the bent lever, and in the second method the diameter of the needle, can be measured with great precision by means of a micrometer.

The length of the tube between the fixed point (P) and the indicating device can be easily measured to three significant figures with an ordinary meter stick.

The temperature of the tube at first may be assumed to be that of the room, and the temperature of the tube when hot will be the temperature of steam, which can be computed from the barometric reading.

Record the measurements and computations somewhat as follows:

Length of metal tube	cm.
Temperature of room	°C.
Height of the barometer	mm.
Temperature of steam	°C.
Length of short arm of pointer	cm.
Length of long arm of pointer	cm.
Magnifying power of pointer	
Reading of pointer before	cm.
Reading of pointer after	cm.
Rise of the pointer	cm.
Actual expansion of the metal tube	cm.
Expansion of tube per degree rise in temperature . .	cm.
Expansion of one centimeter of tube per degree (coefficient of linear expansion)	

Problem. If the melting temperature of aluminum is 1157° F., how much must be allowed for shrinkage in making patterns for aluminum castings? (For coefficient of expansion of aluminum, see tables in Appendix.)

EXPERIMENT 23

CUBICAL EXPANSION OF AIR

What fraction of its volume at 0° C. does a certain quantity of air expand when heated 1° C. under constant pressure?

Glass tube of dry air according to Waterman.
Thermometer.
Meter stick.
Boiler with top.
Bunsen burner.
Pail or battery jar of cracked ice or snow.

A thick-walled glass capillary tube with a uniform bore of about 1 mm. is closed at one end (Fig. 27). Near the middle of the tube is a thread of mercury (*M*) about 2 cm. long. The distance (*AM*) from the closed end of the bore up to the mercury represents the volume of air. (The volume of the air is measured in terms of the volume of a unit length of the tube.)

Fig. 27

Stand the air tube in the battery jar so that the air column is surrounded by cracked ice and allow it to stand until the mercury index ceases to go down further. Then mark the position of the lower end of the thread of mercury with a rubber band. Remove the tube from ice, lay it alongside the meter stick, and measure the distance from the closed end of the bore to the rubber band. This represents the volume of the air at 0° C.

Now put the air tube into the top of the steam boiler, in such a way as to surround the air column with steam. When the mercury ceases to rise in the tube, again mark the position of the lower end of the mercury with a rubber band. Remove the tube from the boiler and measure the distance, which is the length of the air column

when hot. Read the barometer and compute from this the temperature of the steam.

Compute the expansion of the air, the rise in temperature, the expansion per degree rise in temperature, and finally the expansion of 1 *cm.* per degree. This last result represents the coefficient of cubical expansion of air.

Problem. A room 20 m. × 10 m. × 5 m. would contain 1290 kg. of air at 0° C.; how much air will it contain at 30° C.?

EXPERIMENT 24

SPECIFIC HEAT OF A METAL

How many calories does one gram of a metal give out in cooling 1° *C.?*

Blocks of metal, such as aluminum, brass, or copper.
Boiler and burner.
Calorimeter.
Thermometer.
Platform balances and sets of weights.

The thermal unit commonly employed in heat measurements in the laboratory is the **calorie.** This is the amount of heat needed to raise the temperature of one gram of water one degree Centigrade. Experience shows that more heat is required to heat one gram of water one degree than is required to heat one gram of almost any substance one degree. To find out just what fraction of a calorie is absorbed or given out when one gram of a metal changes its temperature one degree is the purpose of this experiment.

If hot metal is plunged into cold water, the metal gives out heat and the water absorbs heat; and if no heat is lost during the process, the number of calories given out

by the metal is equal to the number of calories absorbed by the water. But it must also be remembered that the vessel which holds the water, the **calorimeter**, absorbs heat. Experiments show that brass (the metal commonly used for the calorimeter) absorbs about one tenth as much heat as the same weight of water. Therefore one tenth the weight of the calorimeter, called the **water equivalent** of the calorimeter, is to be added to the weight of water used.

To compute the number of calories absorbed by the water and calorimeter, multiply the number of grams of water plus the water equivalent of the calorimeter by the number of degrees which it is raised in temperature. This quantity of heat was furnished by a certain number of grams of metal in cooling a certain number of degrees. From this we can compute how much heat was furnished by one gram of metal in cooling one degree. This is called the **specific heat** of the metal.

The metal for this experiment may be finely divided like shot, which may be heated in a dipper set in a boiler, or perhaps more conveniently may be in the form of a cylinder or ball which is heated directly in the water of the boiler. Weigh the metal and then put it into the boiler to heat. In the meantime measure out a certain quantity of cold water, about 300 $cm.^3$ at from 5° to 10° C. Record the weight of water used, considering 1 $cm.^3$ as equal to 1 g.

When the metal has reached the temperature of the boiling water, which is to be computed from the barometric reading, first read and record the temperature of the cold water and then quickly lift the metal by means of a thread out of the boiler and put it in the cold water. Stir the water and take its final temperature as soon as it becomes constant.

These data should be recorded in tabular form.

Weight of metal	g.
Weight of cold water	g.
Weight of calorimeter	g.
Temperature of metal	° C.
Temperature of cold water	° C.
Temperature of water and metal	° C.

From these facts calculate the following results :

Water equivalent of calorimeter	g.
Weight of water and water equivalent of cal.	g.
Rise of temperature of water and calorimeter	° C.
Calories absorbed by water and calorimeter	cal.
Drop in temperature of metal	° C.
Calories given out by metal in cooling 1° C.	cal.
Calories given out by 1 g. of metal in cooling 1° C. . . .	cal.

What do you find the specific heat of the metal used to be? Compare this with the result given in the tables in the Appendix and try to explain the difference.

NOTE. Experiments in heat measurements are especially difficult and great precautions must be taken. Each time read the thermometer *correctly* not only to whole degrees, but also to tenths of a degree. Avoid handling the calorimeter during the experiment or in any way transferring heat to or from it. Check up each step in the arithmetical computation.

Problem. A 10-gram ball of platinum (sp. ht. 0.04) is taken from a furnace and dropped into 40 g. of water at 10° C. The temperature is raised to 25° C. How hot was the furnace?

EXPERIMENT 25

COOLING CURVE THROUGH THE MELTING POINT

How does a change of state, such as from a liquid to a solid, affect a cooling curve?

Test tube and clamp.	Acetamide or naphthaline.
Bunsen burner.	Millimeter cross-section paper.
Thermometer.	Boiler.

Fill a test tube about three quarters full of acetamide and place the tube down in the boiling water of the boiler. Insert the thermometer in the test tube and heat until all the crystals are melted and the liquid has reached a temperature of about 100° C. Then lift the test tube out of the boiler and clamp it in a convenient position to observe the temperature as the liquid cools. Do not disturb the liquid or thermometer in any way.

As the substance cools from 100° C. to 50° C., record every half minute the temperature and the time. Then plot these results on cross-section paper, representing *temperatures* by vertical distances (1 mm. for 1°) and *times* by horizontal distances (4 mm. for 1 min.). Study the curve carefully so as to answer such questions as the following:

(a) *What portion of the curve represents the cooling of the substance in the liquid state?*

(b) *What portion of the curve represents the condition during the process of crystallization?*

(c) *What portion of the curve represents the cooling of the substance in the solid state?*

(d) *Is there any part of the curve which indicates "subcooling"?*

(e) *What would you consider the freezing point of the substance used?*

Question. Does the process of freezing water evolve or absorb heat from the surroundings?

EXPERIMENT 26

LATENT HEAT OF MELTING ICE

How many calories are required to change one gram of ice at 0° C. into water at 0° C.?

Calorimeter.	Supply of hot water (teakettle).
Thermometer.	Cracked ice.
Platform scales and set of weights.	Cloth or towel.

First weigh the calorimeter empty and then with about 300 g. of warm water, the temperature of which is about 25° C. above that of the room. Break or grind up enough clean ice to fill a 150-cm.^{3} beaker with pieces less than 2 cm. in diameter. Stir the water in the calorimeter thoroughly and determine its temperature as precisely as possible. At once add the ice, taking care to wipe each piece on the cloth and not to spatter the water. Stir the water continually, and when the temperature of the water has fallen 10° or more below that of the room, stop adding ice and just as soon as the last piece melts, read the temperature again with great precision. To find out how much ice has been used, weigh the calorimeter with its water and melted ice.

Record the following data:

Weight of calorimeter (c)	g.
Weight of calorimeter + water	g.
Weight of water (w)	g.
Initial temperature of water (t)	° C.
Final temperature of water (t')	° C.
Weight of calorimeter + water + ice	g.
Weight of ice (i)	g.

The water and calorimeter in cooling give out heat which is used, *first*, to melt the ice, and, *second*, to raise the water which is formed, from zero to the final temperature. If each gram of ice in changing from ice at 0° C. to water at 0° C. requires x calories, then i grams of ice would require ix calories. But after the ice is melted, it becomes i grams of water at 0° C., and this water is raised to the final temperature t' which requires it' calories in addition. This heat is supplied by W grams of water and by c grams of calorimeter (whose specific heat is about 0.1) in cooling from the initial temperature t to the final temperature t'. This heat is equal to $(w + 0.1\text{ c.})\ (t - t')$ calories. If we make an equation between the *heat absorbed by the ice* and the *heat given out by the water and calorimeter*, we can easily solve for x, the latent heat of melting ice.

Problem. If the latent heat of melting ice is 80 calories, how many B. t. u. are needed to melt 1 lb. of ice?

EXPERIMENT 27

LATENT HEAT OF STEAM

How many calories of heat are liberated when one gram of steam at 100° C. condenses into water at 100° C.?

Boiler and burner.	Calorimeter.
Water trap.	Thermometer.
Balance and weights.	

Fill the boiler half full of water and start heating. Then fill the calorimeter, whose weight has already been determined, two thirds full of cold water (about 5° C.), and determine the weight of the water with great precision.

Set up a book or wooden screen between the boiler and calorimeter and place a thermometer in the water.

As soon as the steam is ready, attach the water trap (*T*, Fig. 28) to the delivery tube to catch any condensed steam. Stir the water in the calorimeter with the thermometer and read its temperature to one tenth of a degree. Then quickly put the delivery tube of the water trap (*T*) into the water so that its end projects under water about 2 cm. Continue to stir the water slowly until the water gets to a temperature about as much above that of the room as the initial temperature was below it. Remove the delivery tube from the calorimeter and after stirring read the highest temperature which the water reaches.

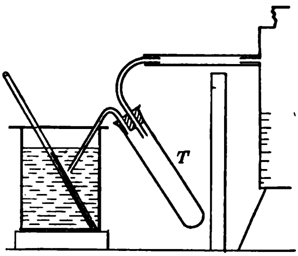


Fig. 28

Finally, as soon as convenient, weigh with great care the calorimeter, water, and condensed steam and compute the weight of the steam used.

Record the following data:

Weight of calorimeter (c)	g.
Weight of calorimeter + water	g.
Weight of water (w)	g.
Initial temperature of water (t)	°C.
Final temperature of water (t')	°C.
Weight of cal. + water + condensed steam	g.
Weight of condensed steam (s)	g.
Water equivalent of calorimeter (0.1 c.)	g.

Computation:

(*a*) How many degrees was the water raised in temperature?

(*b*) How many calories have the calorimeter and water received?

(*c*) How many grams of steam were condensed?

(*d*) How many calories did s grams of condensed steam give out in cooling from 100° C. to t'° C.?

(*e*) How many calories did the s grams of steam give out in condensing?

(*f*) How many calories did one gram of steam give out in condensing to water at 100° C.?

Problem. How many B. t. u. are required to change 100 pounds of water at 45° F. into steam at 212° F.? (Assume the latent heat of steam to be 540 cal. for 1 g. of water at 100° C.).

EXPERIMENT 28

LINES OF MAGNETIC FORCE

What is the direction of the lines of magnetic force which are produced by the earth and a bar magnet?

Bar magnet (15 cm. × 1 cm. × 1 cm.).
Tracing compass (Hahn form).
White paper.
Thumb tacks.
Hard, sharp lead pencil.

Fasten a sheet of white paper to the table with thumb tacks and lay the magnet on the paper near the middle so that its axis lies nearly north and south and its north-seeking pole is turned toward the south. Trace around the bar magnet with a pencil and mark the position of its poles with the letters N and S. Indicate with dots the starting points of about a dozen lines of magnetic force, grouping them mostly around the N-pole.

Place the tracing compass on the paper near the magnet in such a way that the S-pole notch in its rim (see Fig. 29) lies as nearly as possible right over a starting point, and then turn the compass around this point until the needle stands exactly over the line on the compass base. Then mark with a lead pencil the position of the N-pole notch in the rim. Move the compass in the direction in which the N-pole points until the S-pole notch lies exactly over the mark that has just been made. Then turn as before the compass about this point until the needle lies exactly over the north-south line made on the bottom of compass, and again mark the position of N-pole notch. Continue this until the edge of the paper is reached. Connect all these points with a line of dashes and arrows to show the path and direction of the compass. Such a line is called a **magnetic line of force.**

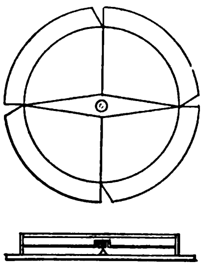


FIG. 29

Draw other lines of force, beginning each time with a point near the N-pole of the magnet.

Draw lines of force which start on the south edge of the paper but do not hit the magnet at all.

On another sheet of paper, repeat this experiment with the S-pole pointing south.

Fold up the sheets of paper and glue them into the regular notebook.

Questions. Are there any points in the magnetic field about the bar magnet where the force of the earth and magnet are exactly equal but opposite in direction? How did you detect them?

EXPERIMENT 29

THE VOLTAIC CELL

How can chemical energy be converted into electrical energy?

Glass tumbler.	Connecting copper wire.
Zinc strip, unamalgamated.	Simple galvanoscope.
Zinc strip, amalgamated.	Large copper plate.
Copper strip.	Zinc wire.
Board top for tumbler.	Porous cup.
2 binding posts.	Copper sulphate solution.
Sulphuric acid (1 : 20).	Zinc sulphate solution.
Commercial sal-ammoniac cell.	

I. **Action of Dilute Sulphuric Acid on Copper and Zinc.** (1) *Open circuit.* Fill a tumbler about three fourths full of dilute sulphuric acid (1 to 20) and put a strip of copper and a strip of zinc into the acid in such a way as to avoid all metallic connections between the strips. Observe for a few minutes the action of the acid on each strip and then record just what is seen on the surface of each metal. (The bubbles are hydrogen.)

(2) *Closed circuit.* Connect the tops of the strips (Fig. 30) and notice what change, if any, takes place on the surface of each metal. Record the results.

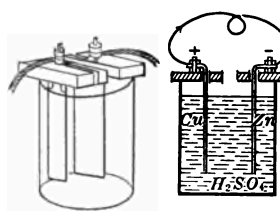
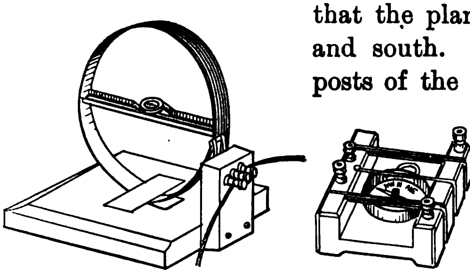


FIG. 30

II. **Effect of using Amalgamated Zinc.** Replace the ordinary zinc which has just been used by an amalgamated zinc plate or rod (*i.e.* zinc which has been dipped in mercury and rubbed until it is covered with a smooth coating of mercury). Repeat the experiment with the circuit open

and closed, and record any differences which are observed in the action.

III. **Magnetic Effects observable about the Wire connecting the Strips.** Place a very simple form of galvanoscope (coil of wire with compass in the center, Fig. 31, *a* or *b*) so that the plane of the coil is north and south. Connect the binding posts of the metal strips by means of copper wire to the binding posts of the 15- or 25-turn coil of the galvanoscope. Assuming that the current comes from the cell by way of the copper strip, note the direction of the current as it goes over the top of the galvanoscope coils and the position of the needle. Reverse the currents in the coils by interchanging the wire connections of the galvanoscope. Observe the new position of the needle due to the change in direction of the current.



(*a*) (*b*)
Fig. 31

IV. **Polarization of a Simple Cell.** Set up the cell as used in III, but use a copper plate of large surface (rolled into cylindrical form) and a very narrow strip or wire of zinc. Arrange the coils of the galvanoscope so that the coils are north and south, and turn the compass so that its zero is directly under the north end of the needle. When all the connections are made, immerse the plates in the acid and read the deflection of the needle *as soon as it stops swinging violently.* (If this deflection is more than about 45° insert into the circuit enough No. 36 German silver wire to reduce the deflection to about 40°.) Tap the galvanoscope lightly

to allow the needle to take its proper position. Watch the needle carefully for two minutes and record what you observe. **Short-circuit** the cell for half a minute by holding a stout, short copper wire in contact with both the copper and zinc plates (Fig. 32). Of course the deflection is reduced nearly to zero because most of the current now goes through the stout copper wire. Remove this wire and see if the needle returns quite to its old value. By short-circuiting the cell, the hydrogen was generated in greater abundance. Judging from this experiment, what effect does an accumulation of hydrogen upon the copper plate seem to have upon the strength of the current? This is known as the **polarization** of the cell.

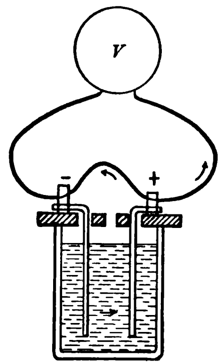


FIG. 32

V. **Daniell Cell.** Replace the simple cell with a Daniell cell, which has the zinc plate standing in zinc sulphate solution and the copper plate in copper sulphate solution and the two solutions separated by a porous cup as shown in Fig. 33. (Fill the porous cup nearly full of zinc sulphate solution and allow it to stand three or four minutes so that the solution fills the pores of the cup and so lets the electricity pass through it easily.) Repeat the experiment of IV and record the behavior of this two-fluid cell. Can the Daniell cell be called a non-polarizing cell? Lift up the copper plate and examine its surface. Does the fact that *copper* instead of hydrogen has been deposited on the copper plate account for the steadiness of the current of the Daniell cell?

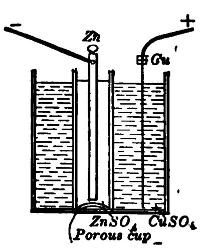


FIG. 33

VI. **Sal-ammoniac Cell.** If time permits, repeat the experiment of IV using a commercial sal-ammoniac cell (zinc and carbon). Does this cell recover after being short-circuited? Break the circuit entirely for a few minutes and then connect and read the deflection.

Question. What kind of cell would you use to operate an ordinary electric bell? Why?

EXPERIMENT 30

MAGNETIC EFFECT OF A CURRENT

What is the direction of the magnetic lines of force about a wire carrying an electric current?

What is the direction of the magnetic lines of force about a coil carrying an electric current?

How is the distribution of magnetic flux passing through a coil changed by inserting a soft iron core?

How should the windings of an electromagnet be connected?

Dry cell.	Compass (2.5 cm. needle).
Reversing switch (or commutator).	Soft iron rod or core.
Connecting wires.	U-shaped iron core.

I. **Magnetic Field about a Wire Carrying Current.** Assuming that the N-pole of the magnetic needle points in the direction of the magnetic lines of force and that the direction in which the electricity flows through a zinc-copper (or zinc-carbon) cell is from zinc to copper (or carbon) inside the liquid and *from copper to zinc in the external circuit*, we will investigate the magnetic field around a wire carrying a current.

(*a*) Connect a simple cell, such as a dry cell, to a reversing switch (Fig. 34) or commutator (Fig. 35) and then lead

the current from south to north over a compass. Close the circuit by closing the switch (or commutator) and record the deflection.

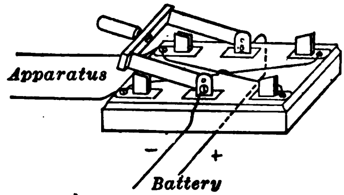


FIG. 34

(*b*) Turn the switch so as to reverse the current, causing it to flow from north to south over the compass. Record the deflection.

Compare these results with what might be expected from the so-called **thumb rule.**

If one grasps the wire with the right hand so that the thumb points in the direction of the current, the fingers will point in the direction of the magnetic field.

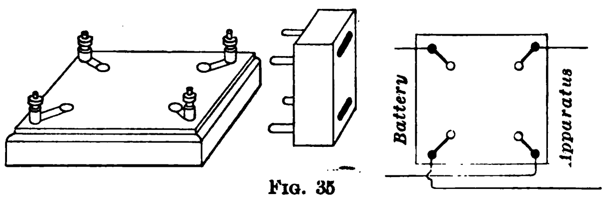


FIG. 35

(*c*) Put the wire under the compass and without changing the direction of the current note the direction of the deflection.

(*d*) Pass the current from the cell over the compass from south to north, holding the wire close to the face of the compass and make the return wire pass under the compass so that a loop is made around the compass. Is the deflection greater or less than in (*a*)? Why?

II. **Magnetic Field about a Coil Carrying Current.** (*a*) Loop the wire used in I (*d*) several times around the compass in such a way that the plane of the coil is north and south.

What change in the deflection is produced by increasing the number of turns in the coil?

(*b*) Make a helix (Fig. 36) by wrapping the wire say fifty times around a lead pencil. Connect this to the switch or commutator as in I, and see whether or not such a helix carrying a current acts as a magnet with one end attracting the north pole of the compass and the other repelling it. Reverse the current through the helix by means of the commutator and record the effect that is produced upon the poles.

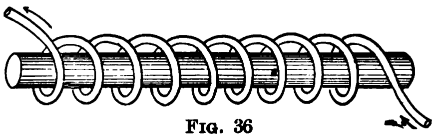


FIG. 36

Compare these results with what might be expected from the **thumb rule for a coil.**

Grasp the coil with the right hand so that the fingers point in the direction of the current in the coil, and the thumb will point to the north pole of the coil.

(*c*) Make an electromagnet by putting a large iron nail or bolt inside the helix. Does this iron core make the poles stronger or weaker than before? How do you know?

(*d*) Wind the two sides of the U-shaped piece of iron with a wire carrying a current, in such a way that one end which has been already marked shall be an N-pole and the other an S-pole.

Test the polarity of this horseshoe with a compass.

In recording the results of these experiments make very simple but clear diagrams, showing the polarity and the direction of the current in each case.

Question. An ordinary twisted lamp cord, connected to a lighted electric reading lamp, passes over a pocket compass. What effect will the current have on the magnetic needle?

EXPERIMENT 31

ELECTROMOTIVE FORCE

How does the E. M. F. of a cell depend upon the size and character of the electrodes and on the solution or electrolyte? How does the E. M. F. of a group of cells depend on their arrangement (series and parallel)?

D'Arsonval galvanometer and high resistance coil (1000 ohms), or voltmeter (0–5).
Simple voltaic cell (Exp. 29).
Carbon rod or plate for cell.
Lead rod or plate for cell.
Sulphuric acid (1:20).
Hydrochloric acid dil.
Brine, solution of common salt.
2 Dry cells.
Connecting wires.
Connectors for joining wires.

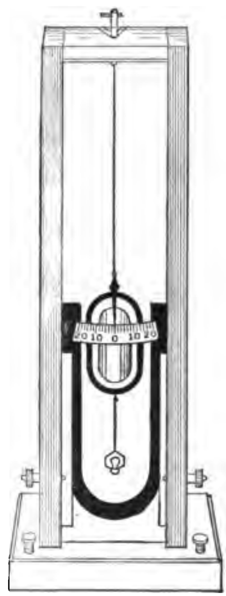


FIG. 37

In order to compare the **electromotive forces**, or the **electric pressures** of cells, we may compare the currents which they send through a high resistance galvanometer. A very convenient galvanometer for this purpose is the d'Arsonval galvanometer (Fig. 37), which consists essentially of a horseshoe steel magnet with a coil of many turns of fine copper wire hung between the poles. The coil is suspended so that the plane of the coil is parallel to the line joining the poles, but when a current, even a very slight current, is sent through the coil, it is turned because it acts as an electromagnet and its poles are attracted and repelled by the poles of the horseshoe magnet. In this experiment we shall connect in series with the galvanometer

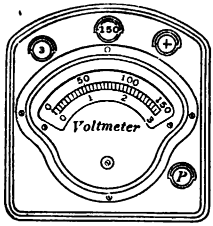


FIG. 38

a coil of small German silver wire having a resistance of about 1000 ohms. Such a galvanometer may be replaced by the more convenient **voltmeter** (Fig. 38), which is simply a portable d'Arsonval galvanometer with a high resistance coil in series.

I. **Effect of Size of Cell on the E. M. F.** Connect a simple cell, such as used in Exp. 29, with the galvanometer having the high resistance in series. Note the deflection of the needle which is attached to the movable coil. Then move the plates as far apart as possible in the jar and again note and record the deflection. Finally lift the plates almost out of the liquids and record the deflection.

What effect does the distance between the plates and the area of the plates immersed seem to have on the electromotive force of a cell?

II. **Effect of Using Different Metals on the E. M. F.** Note the direction and amount of the deflection caused by the zinc-copper cell. Remove the copper plate and insert a carbon plate or rod and again note the direction and amount of the deflection. If the deflection is in the same direction as above, it shows that the carbon is positive (+) with respect to zinc; but if it is in the opposite direction, then the zinc is positive (+) with respect to the carbon. In the same way test the following pairs of metals as electrodes: zinc-lead, lead-copper, and lead-carbon.

Which pair gives the highest E. M. F.?

Is there any metal among those investigated that is positive with respect to some metals and negative with respect to others?

III. **Effect of Different Liquids (Electrolytes) on the E. M. F.** Note again the amount and direction of the deflection when zinc and copper are immersed (*a*) in dilute sulphuric acid; (*b*) in dilute hydrochloric acid (HCl); (*c*) in a solution of common salt ($NaCl$); (*d*) in water (H_2O).

The plates should be thoroughly rinsed off before placing them in a new liquid.

What is the effect of the different liquids used as electrolytes on the E. M. F. of the cell?

IV. **Effect of Series and Parallel Arrangement on the E. M. F.** Using the high resistance coil in series with the galvanometer, connect two similar cells (such as dry cells) in *series*, that is, connect the zinc of one to the copper (or carbon) of the other as shown in Fig. 39 and record the deflection.

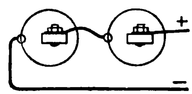


Fig. 39

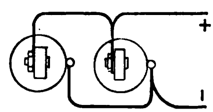


Fig. 40

Then connect the same cells in *parallel*, that is, zinc to zinc and copper to copper, as shown in Fig. 40, and again read and record the deflection.

Compare these results with the deflection of a single cell.

What is the effect of the series arrangement on the E. M. F?
What is the effect of the parallel arrangement on the E. M. F?

Question. Six storage cells, 2 volts each, are connected in two rows of three cells each. The three cells in each row are joined in series, and two rows of cells are joined in parallel. What is the E. M. F. of this arrangement?

EXPERIMENT 32

THE FALL OF POTENTIAL ALONG A CONDUCTOR

When a steady current is flowing along a conductor, how does the fall of potential ("voltage") between two points vary with the resistance?

When the resistance remains fixed, how does the fall of potential depend upon the current?

Low resistance galvanometer or ammeter (0–5 amp.).
1-meter high-resistance wire stretched along a meter stick.
Storage battery (3 cells) or other source of steady current, such as Daniell cells.
Voltmeter (low range) or high resistance galvanometer.
Variable rheostat.

I. Potential Difference across Equal Resistances. Connect one meter of high resistance wire in series with a low reading ammeter (A), an adjustable resistance (R), and a source of steady current, such as a battery of storage or Daniell cells (Fig. 41). Make the connections such that the current enters

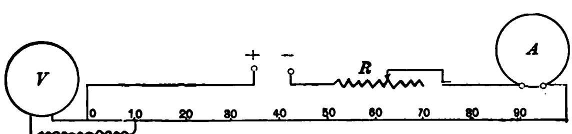


FIG. 41

at the end marked 0 and adjust the resistance so that the current is one ampere. Touch the + terminal of a low reading voltmeter (V) to the 0 terminal of the wire and touch the other terminal firmly against the wire at a point just 10 cm. from the 0 terminal. Read carefully the voltmeter and record this as the **potential difference** or **difference in electrical pres-**

sure between the ends of this 10-cm. length of wire. In the same way measure the fall of potential (or voltage) from 10 to 20, 20 to 30, etc., *i.e.* for each 10-cm. length along the wire. Assuming the wire is of uniform cross section, how do the resistances of equal lengths compare? *What conclusion can you draw regarding the drop in potential for equal resistances and the same current?*

II. **Potential Difference across Varying Resistances.** Connect the + terminal of the voltmeter to the 0 end of the wire and place the other terminal successively at 10, 20, 30 cm., etc., and record the voltage for each case. How does the resistance of 20 cm. of wire compare with the resistance of 10 cm.? How does the drop in potential (or voltage) across 20 cm. of wire compare with that across 10 cm.? Compare the resistances and voltages for 40 cm. and 80 cm. lengths in the same way.

When the current is constant in a conductor, how does the drop in potential depend on the resistance?

III. **Effect of Varying Current on Potential Difference.** Measure the voltage across 50 cm. of wire when the current is 0.5 ampere and then 1.0, 1.5, 2.0, 2.5, and 3.0 amperes.

How does the fall of potential in any given conductor vary with the current flowing?

Upon what does the drop in potential across any given conductor depend?

NOTE. The terms "drop in potential" and "potential difference" as used in this experiment mean the same thing — "voltage."

Problem. A generator is sending 7.5 amperes through two resistances, 8 ohms and 10 ohms in series. What is the voltage across the 8-ohm resistance? What is the voltage across the 10-ohm resistance? What is the voltage across both resistances?

EXPERIMENT 33

DETERMINATION OF RESISTANCE BY USE OF AMMETER AND VOLTMETER

How should the ammeter be used to measure current (a) *in two coils in series,* (b) *in two coils in parallel?*
How should the voltmeter be used to measure the voltage (a) *across two coils in series,* (b) *across two coils in parallel?*
How can we compute the resistance of (a) *each of the two coils and* (b) *of the two coils in parallel?*

110-volt direct current line or storage battery.
Two resistance coils of manganin wire, or Ia Ia wire.
Fuses.
Voltmeter (0–150).
Ammeter (0–15).

I. **Measurement of Current.** Join the two coils in series and connect with the 110-volt D.C. service or other supply of steady current. Place the ammeter (*a*) between coil 1 and the power, (*b*) between coil 1 and coil 2, (*c*) between coil 2 and the power. Record the average reading of the ammeter in each position. What do you conclude about the current in a series circuit? Where should the ammeter be placed in a series circuit?

Join the two coils in parallel and measure the current with the ammeter (*a*) in the line between the coils and the power, (*b*) in the circuit of No. 1 alone, and (*c*) in the circuit of No. 2 alone. Compare the sum of currents in (*b*) and (*c*) with the current in (*a*). Where must the ammeter be placed to measure the current in a branch circuit?

II. **Measurement of Voltage.** With the coils in series, measure the voltage across (*a*) the two coils together and (*b*) each coil alone. Take the average reading of the volt-

meter. Compare the sum in (*b*) with the reading in (*a*). What is the effect upon the current flowing through each part of a series circuit, if the resistance of any unit is decreased?

Connect the two coils in parallel and take the voltage between the binding posts of each coil. Compare these readings. Assuming a constant voltage service, what will be the effect upon the voltage across the group if the resistance of one coil is decreased? Upon the current flowing along that coil? Upon the current in the other coil? In the line?

III. **Computation of Resistance.** From the readings in Part I and II, compute, using **Ohm's Law**, the resistance of each coil and the joint resistance of the two coils in parallel. Compare this latter result with that obtained by computing the joint resistance from the separate resistances. In recording the data of this experiment, make careful diagrams to show the connections.

Problem. A circuit has two branches, one of 2 ohms, the other of 12 ohms. The current in the 2-ohm branch is 5 amperes. What difference of potential is maintained between the terminals of the circuit? What current flows in the second branch?

EXPERIMENT 34

MEASUREMENT OF RESISTANCE BY WHEATSTONE BRIDGE

How can resistances be compared by a Wheatstone bridge? What is the resistance of 50 ft. of No. 30 copper wire?

2 dry cells.	D'Arsonval galvanometer.
Key.	Resistance box or known resistance coils.
Wheatstone bridge.	50-ft. coil of No. 30 copper wire.

The Wheatstone bridge consists essentially of a loop of four resistances, indicated in Fig. 42 as R, X, m, and n. When the key, K, is closed, the current from the cells flows into the loop at A, and there divides so that part (I_1) goes through AC and part (I_2) through AD. A sensitive galvanometer (G) is connected between C and D. Then the resistances R, X, m, and n are so adjusted that no current flows through the galvanometer, which means that all of I_1 has to go on through CB and all of I_2 through DB, and also that C and D are "equipotential" points. When this adjustment has been made,

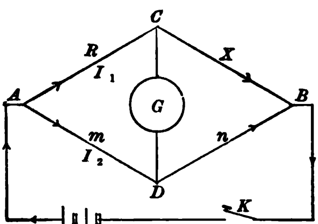


FIG. 42

the voltage drop across $AC = I_1R$,

and the voltage drop across $AD = I_2m$.

But since C and D are at the same potential, these voltage drops are equal, and

$$I_1R = I_2m. \quad (1)$$

For similar reasons

$$I_1X = I_2n. \quad (2)$$

Dividing equation (1) by equation (2), we have

$$\frac{R}{X}=\frac{m}{n}.$$

From this fundamental equation of the Wheatstone bridge, if we know *R*, *m*, and *n*, we can compute *X*.

In the form of this apparatus shown in Fig. 43, the resistance *ADB* consists of a wire of uniform cross section and one meter long. Since the resistances *m* and *n* are then directly proportional to the distances *AD* and *DB*, the equation becomes

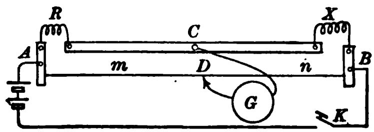


FIG. 43

$$\frac{R}{X}=\frac{\text{Distance AD}}{\text{Distance DB}},$$

where *R* is a known resistance such as a resistance box, and the distances *AD* and *DB* are read off on a meter stick. It will be helpful to remember that

$$\frac{\text{Left Resistance}}{\text{Right Resistance}}=\frac{\text{Left Distance}}{\text{Right Distance}}.$$

Connect the apparatus, as shown in Fig. 43, using a 50-ft. coil of No. 30 copper wire in position marked *X*. When the key in the battery circuit is closed, the current comes to *A* where it divides, part going through the known resistance *R*, along the bar of the bridge (whose resistance is negligible), and through the unknown coil *X* to *B*; the other part going by way of the German silver wire *ADB* to *B*. If the known resistance is made in the form of a resistance box, we may remove the 10-ohm plug, place the slider *D* connected to the galvanometer in the middle of the German silver wire, and make contact for an instant

only. If the galvanometer needle moves, it shows that the two points C and D are at different potentials. First try another value for R, say 1 ohm, and if the galvanometer needle swings the other way when contact is made at D, it shows that X, the unknown resistance, lies between 1 and 10 ohms. By trial just as in weighing make a balance between R and X. When it is approximately balanced, make the fine adjustment by sliding D back and forth along the wire until the galvanometer shows no current flowing when the contact is made at D. From the above equation compute the resistance of 50 ft. of No. 30 copper wire.

Repeat the experiment twice, using slightly different values for R, the known resistance. Find the average or mean value of these three results and compute from this the resistance of 1000 feet of No. 30 copper wire. Compare this with the result given in the Wire Tables in the Appendix.

Problem. In testing a certain Wheatstone bridge, a standard 5-ohm coil is placed at R and a standard 4-ohm coil at X. What is the correct position of D, *i.e.* what are the correct values for m and n?

EXPERIMENT 35

INTERNAL RESISTANCE OF A BATTERY

What is the effect on the current of decreasing the size of the plates of a cell and the distance between them?
When the external resistance is small, what effect does it have on the current to arrange cells (a) *in series and* (b) *in parallel?*
How can we measure the internal resistance of a cell?

Daniell cell.
Ammeter or low resistance galvanometer.
Two dry cells.
High resistance wire such as No. 36 G. S. wire.

In this experiment we shall consider only cases where the external resistance is small. To measure the current we shall use an ammeter or galvanometer with low resistance.

I. **Effect of Internal Resistance on Current Furnished by a Cell.** Connect a Daniell cell to an ammeter and observe the effect of bringing the zinc and copper plates (*a*) near together and (*b*) far apart. What effect on the internal resistance of a cell does it have to increase the distance between the plates?

Gradually lift the plates out of the liquid and record the effect on the current. What effect on the internal resistance of a cell does it have to diminish the area plates immersed?

II. **When the External Resistance is Small, what Combination of Cells gives the Greatest Current?** (*a*) Connect two similar cells in series with an ammeter and record the current. Compare this with the current furnished by one cell. How do the results of this experiment compare with results of testing the E. M. F. of two cells in series (Exp. 31)?

(*b*) Join two cells in parallel and observe the current. Compare this with the current strength of one cell. How do these results compare with the E. M. F. test of two cells in parallel? How do you explain this difference?

III. **Measurement of Internal Resistance.** Connect a Daniell cell with an ammeter and record the current. Introduce into the circuit some high resistance wire, such as No. 36 German silver wire, sufficient to reduce the current to just one half its former value. Measure the length of the German silver wire used and calculate from the specific resistance of the wire the resistance thus introduced. Assuming the E. M. F. of the cell to have remained constant, in order to reduce the current to one half, the resistance must have been doubled. This means that the internal resistance of the cell is equal to the resistance of the German silver wire which has been inserted.

The internal resistance of cells arranged in series or in parallel can be computed just like the resistance of several wires in series or in parallel; that is, the series arrangement multiplies the internal resistance and the parallel arrangement divides the internal resistance of one cell by the number of cells.

How should cells be connected to get a large current when the external resistance is small? When the external resistance is large?

Problem. A telegraph sounder has a resistance of 70 ohms and requires 0.2 ampere to work it. How many gravity cells, each of 1.1 volts and 3.0 ohms, will be required?

EXPERIMENT 36

MEASUREMENT OF CURRENT BY A COPPER COULOMBMETER

How may an ammeter be checked by the weight of copper deposited in a certain time?

Copper coulombmeter.
Copper sulphate ($CuSO_4$) solution with a little sulphuric acid and alcohol.
Ammeter.
Adjustable resistance.
Watch or clock with second hand.
Beam balance and weights.
Storage battery or supply of steady current.

The copper coulombmeter consists of a glass jar with two anode plates (*A*, *A*) and one cathode (*C*) or gain plate placed between them (Fig. 44). About 50 cm.[2] of cathode surface is allowed for each ampere of current, and the liquid is a solution of copper sulphate ($CuSO_4$), slightly acidulated with sulphuric acid (H_2SO_4) and containing a little alcohol. The gain plate (cathode) is first made perfectly clean by rubbing with fine emery until bright, and then wiping with a clean dry cloth. After it is cleaned, the part which is to be immersed must not be touched by the fingers.

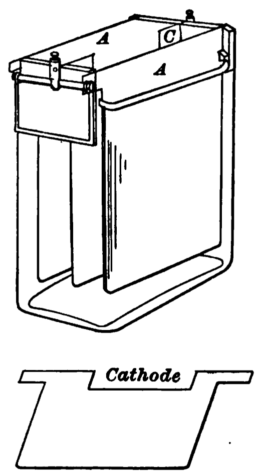


FIG. 44

Weigh this clean cathode as accurately as you can and set it aside.

Connect the ammeter to be checked with an adjustable resistance in circuit with the coulombmeter and some supply of steady current such as a storage

battery. Insert in the coulombmeter a trial cathode plate, not the clean one, but the same size as the one to be used. The current must be made to enter at the outside plates (anodes) and emerge at the middle or gain plate (cathode) (Fig. 45). Close the circuit and adjust the resistance to give the desired current (from 1 to 2 amperes).

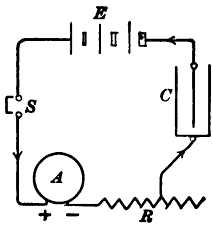


FIG. 45

Open the circuit and replace the trial cathode by the clean weighed cathode and again close the circuit, noting exactly the time (hr. min. sec.). Record the ammeter reading every ten minutes and keep the current constant. After 30 or 40 minutes, break the circuit and at once remove the gain plate. Note the deposit of copper. Rinse off in clean water and then in alcohol and dry quickly. Reweigh and determine the gain as precisely as possible.

Compute the gain in weight per hour.

Assuming that 1.186 g. of copper is deposited by one ampere in one hour, *compute the average current.*

Compare this value of the current with the average reading of the ammeter.

Problem. How many ounces of copper would be deposited from a solution of copper sulphate in 10 hours by a current of 2.5 amperes?

EXPERIMENT 37

INDUCED CURRENTS

How may currents be induced by means of a magnet?
How may currents be induced by an electromagnet?
How may a conductor be moved in a magnetic field to generate a current?

D'Arsonval galvanometer.	Bar magnet.
2 dry cells.	Soft iron core.
2 coils of about 800 turns No. 28 copper wire.	Reversing switch.
	U-shaped steel magnet.

I. **Induction by a Magnet.** To see which way the needle of the d'Arsonval galvanometer turns when the current enters at the right-hand binding post, we may short-circuit the instrument with a stout copper wire and connect with a simple cell so that the current enters at the right terminal of the galvanometer. Place a piece of paper near the instrument and record the direction of the deflection with an arrow when the right terminal is made positive (+). Connect to the galvanometer (now without any shunt) a coil of many turns (say 800 turns of No. 28 copper wire).

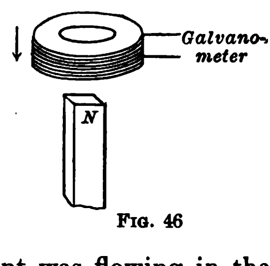


FIG. 46

(*a*) Now move the coil downward quickly over the N-pole of the bar magnet (Fig. 46), and record the direction and amount of the deflection. From this deflection, determine the direction of the current induced in the coil. While this current was flowing in the coil, it made the coil a temporary magnet. What was the polarity of the side of the coil approaching the N-pole of the magnet?

(*b*) Quickly remove the coil from the magnet and record the direction and amount of the deflection. Compare the direction and amount of the current thus induced with that in part (*a*). What is the polarity of the end of the coil that last leaves the magnet's N-pole?

(*c*) Repeat (*a*) and (*b*) using the S-pole of the magnet and in each case determine the direction of the current induced in the coil. *Is the direction of the induced current such as to oppose or to assist the motion of the coil?*

II. **Induction by an Electromagnet.** Insert an iron rod in a coil *S* which is connected to the galvanometer. Connect through a commutator one or two dry cells to a similar coil *P* which is placed on the iron rod beside coil *S*.

(*a*) Now close the circuit by the commutator or switch and record the deflection of the galvanometer. From this determine the direction of the current induced in the coil S. Was this current induced in coil *S* (called the secondary) in the same direction as the current in coil *P* (called the primary)? Explain how this might be expected from the experiment in Part I.

(*b*) Break the circuit at the commutator and note direction and amount of the deflection. Compare this with that induced when the circuit is closed.

Is the induced current in the same or in the opposite direction to that which is flowing in the primary coil? Note that the current is induced by the *changes* in the magnetism of the electromagnet. *Is the direction of the induced current such as to oppose or assist the changes in the magnetism of the iron core?*

III. **A Current Generated by Moving a Conductor across a Magnetic Field.** Hold the coil *S* which is connected to the galvanometer between the poles of a horseshoe magnet in

such a way that the plane of the coil is at right angles to the line joining the poles (Fig. 47). Quickly turn the coil a quarter turn so that the plane of the coil is parallel to the magnetic field. Observe the direction of the induced current. After the galvanometer has come back to zero, rotate the coil another quarter turn and note the direction of the induced current. In a similar manner continue to rotate the coil one quarter turn at a time. *In what position is the coil when the induced current is reversed?*

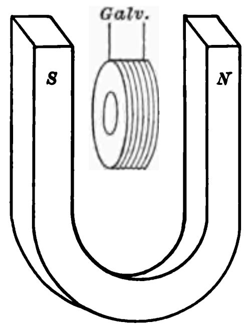


FIG. 47

NOTE. In this experiment it will be helpful to record the results in the form of very simple sketches showing the direction of the motion and induced current and polarity of the magnet.

Question. A coil is rotated in a magnetic field in such a way that *no* current is induced. What is the direction of its axis of rotation?

EXPERIMENT 38

EFFICIENCY OF AN ELECTRIC MOTOR

What is the ratio of the mechanical output of an electric motor to the electrical input?

0.25 horse power motor.
110-volt direct current line or storage battery.
Ammeter.
Voltmeter.
Two spring balances and support.
Cord or strap for brake.
Speed counter.
Watch.

Connect a small D. C. motor to some supply of electric current. Insert an ammeter in the line to measure the in-

tensity of the current I and put a voltmeter across the brushes (Fig. 48) to get the electrical pressure E. From these two factors we may easily compute the **input** in watts which is equal to the *product* of *volts times amperes*.

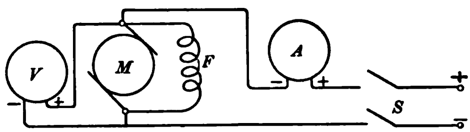


FIG. 48

To get the mechanical **output** we may make a **brake test.** A very simple form of brake consists of a belt or cord attached to two spring balances and passing under a pulley on the motor shaft, as shown in Fig. 49. If the motor rotates clockwise, as indicated, it is evident that the spring balance A will have to exert more force than balance B because of the friction of the pulley on the cord. The amount of this friction is equal to the difference between the readings of A and B, and it is exerted each minute through a distance equal to the circumference of the pulley times the revolutions per minute. The *work done in one minute* is equal to the *friction times the distance per minute.*

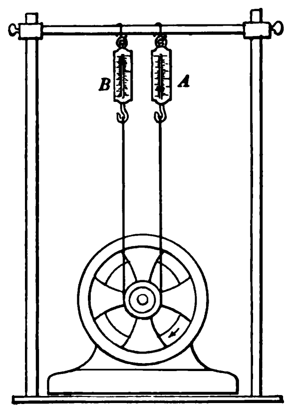


FIG. 49

First determine the circumference of the pulley by measuring the length of fine wire required to make one turn around the pulley. To determine the number of revolutions per minute, hold a speed counter (Fig. 50) against the end of the motor shaft (S) for just one minute.

When all the apparatus is assembled, start the motor by closing the switch. Throw on the load by increasing the

tension on the brake cord so as to slow down the motor a little. Keeping this pull steady, we get the speed of the motor and at the same time read the spring balances, ammeter and voltmeter. Then repeat this experiment, putting more load on the motor by pulling more strongly on the balances. Finally, make a third trial with still more load on the motor.

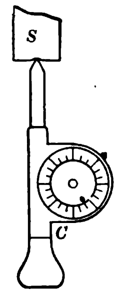


FIG. 50

It will be convenient to record the data and results in tabular form, somewhat as follows:

	FIRST TRIAL	SECOND TRIAL	THIRD TRIAL
Voltmeter reading			
Ammeter reading			
Watts *put in* motor			
Number of revolutions per minute			
Distance meters per minute			
Balance A reading (kg.)			
Balance B reading (kg.)			
Friction $(A - B)$ (kg.)			
Work *got out* of motor (watts)			
Efficiency %			

It will be helpful to know that 1 watt = 6.12 kilogram-meters per minute.

Does the efficiency of the motor change when the load is changed? Why does the amount of current supplied to the motor change as the brake load increases?

Problem. At 10 cts. per K.W.-hour, how much will it cost per week of 54 hrs. to run a motor, having an average load of 10 H.P., and an average efficiency of 90 %?

EXPERIMENT 39

HEATING EFFECT OF AN ELECTRIC CURRENT

How many joules of electrical energy are equivalent to one calorie of heat?

Calorimeter and stirrer.	Ammeter.
32 c.p. lamp and socket.	Voltmeter.
Platform scales and weights.	Source of current, 110 volt service or storage battery.
Thermometer.	Watch or clock with second hand.
Connecting wires.	

Weigh a calorimeter with its stirrer. Then pour in enough water at about 10° C. below the room temperature to cover the bulb of a 32 candle power lamp and weigh the beaker again to get the weight of the water. Insert the lamp bulb and a thermometer in the calorimeter (*C*) and connect an ammeter (*A*) in series with the lamp (*L*) and a voltmeter (*V*) in shunt with the lamp as shown in the Fig. 51. Stir the water and note its temperature and then turn on the current at *S*, noting precisely the time of doing so.

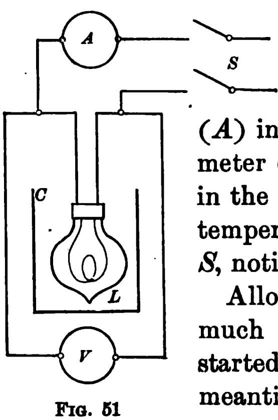


FIG. 51

Allow the water to be heated about as much above the room temperature as it started below, stirring continually. In the meantime read the voltmeter and ammeter every two minutes. When the current is cut off, note the time and the highest temperature to which the water rises.

Record the data and results in tabular form as follows:

Observations

Weight of beaker and stirrer	g.
Weight of beaker, stirrer, and water	g.
Temperature of water at start	°C.
Time of start (hr. min. sec.)	
Temperature of water at finish	°C.
Time of finish (hr. min. sec.)	

Volts	Amperes
. . . . . .	. . . . . .
. . . . . .	. . . . . .
. . . . . .	. . . . . .

Calculated Results

Weight of water + water equivalent of calorimeter . . . .
Rise in temperature . . . .
Calories of heat absorbed . . . .
Time of run in seconds . . . .
Average volts . . . .
Average amperes . . . .
Joules (watt-seconds) delivered to lamp . . . .
Number of joules per calorie . . . .

Problem. Assuming that one joule (watt-second) is equivalent to 0.24 calorie, compute the price per calorie for the heat generated in an electric iron using 3.5 amperes at 110 volts. The cost of electricity is 10 cts. per K.W.-hour.

EXPERIMENT 40

FREQUENCY OF A TUNING FORK

How many vibrations does a tuning fork make in one second?

Tuning fork.
Recording apparatus (Fig. 52).
Glass plates.
Stop watch.
Alcohol lamp filled with turpentine and alcohol.
Bristles or stiff paper points.
Wax.
Releasing clamp for tuning fork.
Thin shellac.

Since a tuning fork, which gives a musical sound, vibrates too fast to be counted directly by the eye, it is necessary to use a special apparatus, such as shown in Fig. 52. This very simple *chronograph* consists of three parts: a smoked plate or paper (*P*), a tuning fork (*F*), with a fine wire or paper point attached to one prong, and a short pendulum (*M*), which also has a wire point projecting so as to touch the glass plate. The smoked glass plate is drawn along in a straight line beneath the pointer of the vibrating tuning fork and at right angles to the direction of the vibrations, so as to make a wavy curve on the glass, and at the same time the pendulum point vibrates back and forth across this curve. If, then, we know the rate of vibration of the pendulum per second, we can easily count on the smoked glass the number of vibrations of the fork corresponding to any number of swings of the pendulum, and thus compute the number of vibrations of the fork per second.

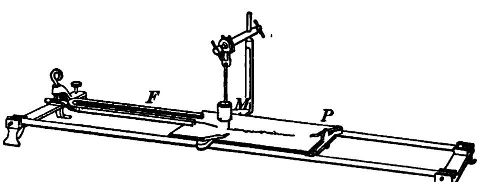


FIG. 52

Clamp the tuning fork so that its tracing point is only a few millimeters from the point of the pendulum. The line of these two tracing points should be parallel to the direction in which the glass is to move. The tracing points must rest lightly on the smoked glass surface and yet hard enough to scratch away the coating. To test this, set the fork and pendulum in vibration with the glass at rest. A good way to set the fork vibrating is to squeeze the prongs together with a little U-shaped metal clamp and then quickly pull the clamp off.

When the apparatus is properly adjusted, start the pendulum swinging and set the fork vibrating and then draw the glass along the track at such a rate as to have at least one *complete* swing of the pendulum recorded on the glass. Several sets of tracings may be recorded on the same plate by moving it a little sideways, and so bringing a fresh surface under the tracing points.

To get the rate of the pendulum, set it swinging and count its vibrations for one minute. Compute the number of vibrations of the pendulum per second.

Next count the number of vibrations of the fork corresponding to a full vibration of the pendulum, *i.e.* the number of

FIG. 53

vibrations traced by the fork between the points A and C (Fig. 53) or between B and D, estimating in every case to tenths of a vibration.

Compute the number of full vibrations made by the fork per second.

Question. In this experiment what is the effect on the curve traced if we move the smoked plate more rapidly?

NOTE. If the tracings are made on smoked paper, they may easily be "fixed" by pouring over the smoked surface a very thin solution of shellac. After a few minutes the paper is dry and may be pasted in the notebook as a part of the record of the experiment.

Since smoked glass is always more or less dirty, the glass is sometimes covered with a thin coat of whiting in alcohol.

EXPERIMENT 41

WAVE-LENGTH OF SOUND

How long is the sound wave in air emitted by a vibrating tuning fork?

How fast does the sound wave travel in the air of the room?

Tuning fork ($n = 512$).
Hydrometer jar of water.
Resonating tube.
Large flat cork.
Meter stick.
Rubber bands.

Place the resonating tube in the hydrometer jar and pour in water so as nearly to fill the jar. Strike one prong of the tuning fork on a large cork stopper and hold the vibrating fork over the open end of the tube (Fig. 54). By raising the tube slowly out of the water, a point will be found where the air-column is of just the right length to reinforce the fork. Mark with a rubber band around the tube the position of the water where the sound was loudest. Then set the fork in vibration again and by raising and lowering the tube and listening intently, determine again as precisely as you can the point where the air-column gives the greatest reinforcement. Measure the length of the air-column.

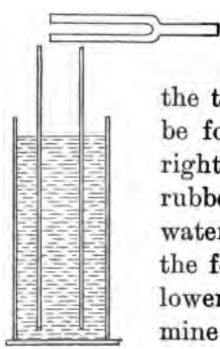


FIG. 54

In a similar manner find a second position of the water surface nearer the bottom of the tube, which also gives rein-

forcement to the sound. Measure the length of this air-column and record the temperature of the air.

The length of the short air-column (plus about 0.3 the internal diameter of the tube) is equal to *one fourth* the wave-length of the tone of the fork in air. The difference between the length of the short and long air-columns is equal to *one half* a wave-length.

Compute this difference in length between the two air-columns and the length of a wave emitted by the fork used.

Given the frequency of the fork, *i.e.* the number of vibrations per second, compute the velocity of sound at the temperature of the room, using the wave-length just determined.

It is usually stated that the velocity of sound in air is 1087 feet per second at 0° C. and that it increases about 2 feet per second for each degree C. rise. Compare this value with the result of your experiment and compute the percentage error.

Problem. What is the pitch of a closed organ pipe 62 cm. long on a day when the temperature is 20° C.?

EXPERIMENT 42

BUNSEN PHOTOMETER

What is the candle power of a given electric lamp bulb in terms of a standard lamp?
What is the intensity of a Tungsten lamp?
What is the effect on the downward intensity of an electric lamp of adding a shade?

Bunsen photometer in a dark room or in a light-tight box.
Three incandescent lamps (one Tungsten lamp, and one of known candle power).
Voltmeter.
Ammeter.
Shade for electric bulb.

Set up a Bunsen photometer in a darkened room, as shown in Fig. 55. Use a standard 16 candle power bulb (*S*) as a basis for comparison. Insert a rheostat in the power

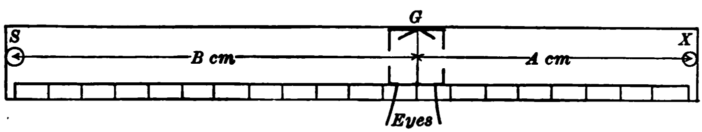


FIG. 55

circuit so as to bring the standard lamp to its required voltage. At the other end of the photometer, about 200 cm. from the first lamp, set up another electric lamp (*X*) which is to be tested. Between these two lamps place the sight box or screen (*G*) with the grease spot. This screen is to be moved back and forth between the lights until a position is found such that the screen is equally illuminated on both sides, that is, such that the central spot or disk and the surrounding rim of paper are of the same brightness. Since it

is difficult to set this sight box or screen precisely, several trials should be made and the average position taken.

Suppose that the lamp X to be tested is found to be A cm. from the screen and the standard lamp S equally illuminates the screen when B cm. away. If the distances A and B are equal, then the candle powers of the two lamps are the same; but if these distances are not equal, the lamp which is farther from the screen has the greater candle power. Furthermore, since the intensity of illumination decreases as the square of the distance, *the candle powers of the two lamps are directly proportional to the squares of their distances from the screen.* That is,

$$\frac{X}{S} = \frac{A^2}{B^2}.$$

In this way, knowing S and measuring A and B, we can compute X. Find the candle power of an ordinary electric lamp bulb; that is, the **mean horizontal candle power.** From the readings of the voltmeter and ammeter in the lamp circuit, compute the cost of maintaining such a lamp for one hour and the cost per candle power.

Similarly, find the candle power of a 50-watt Tungsten lamp.

Finally, turn an incandescent lamp into such a position as to measure its candle power downward both with and without a shade.

Problem. If a 16 candle power lamp is 85 cm. from a Bunsen photometer screen, how far must a 20 candle power lamp be on the other side, when the screen is properly adjusted?

EXPERIMENT 43

IMAGE IN A PLANE MIRROR

How does the angle of incidence compare with the angle of reflection?

How does the image in a plane mirror compare with the object in respect to size, distance, and form?

Plane mirror.
Block for holding mirror with rubber bands.
Paper.
Protractor.
Ruler.
Block with vertical black line on one face.

I. **Reflection in a Plane Mirror.** Draw a straight line across a sheet of paper and label this the *Mirror Line*. Set up the mirror so that its reflecting surface is exactly over this line. At a distance of 10–15 cm. in front of the mirror, make a dot and label it *O*. Place the small block with its vertical black line standing directly over this dot. To locate the image of this line lay a ruler on the paper so that its edge points directly at the image. Care should be taken to *sight* with one eye only along the edge of the ruler and then draw a clean sharp line along the edge that points toward the image. To make sure that the ruler has not slipped in this process, remove the ruler and look along the surface of the paper and see if the line does really point at the image. If not, erase the line and try again.

Place the ruler on the other side of the small block and make another *sight line* just as before, making sure that the mirror still has its reflecting surface just on the mirror line.

Remove the mirror and block and continue each of the sight lines as solid lines up to the mirror line and then continue them as dotted lines behind the mirror until they meet.

Mark this point of intersection, *I*, the image-point. The solid sight lines represent **reflected rays.** From the object-point, *O*, draw lines to the intersection of each of these sight lines with the mirror line. These lines from *O* to the mirror represent the **incident rays.** Connect the object-point, *O*, with the image-point, *I*, making it solid in front of the mirror and dotted behind the mirror. Indicate the direction in which light travels along the lines by arrows, as in Fig. 56.

At one of the points of reflection erect a **normal,** that is, a perpendicular to the mirror, and label the angle between the incident ray and this normal the **angle of incidence,** and the angle between the reflected ray and the normal the **angle of reflection.**

Distance of object from mirror	cm.
Distance of image from mirror	cm.
Angle between *OI* and the mirror line	°
Angle of incidence	°
Angle of reflection	°

II. **Image in a Plane Mirror.** On another sheet of paper draw a line across the middle and set up the mirror as be-

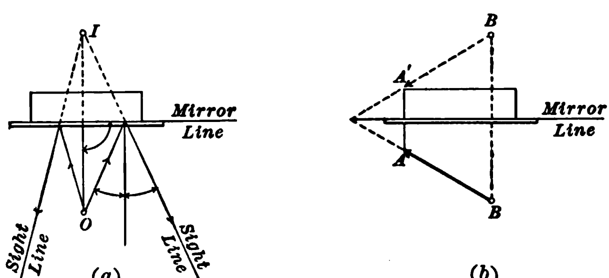


FIG. 56

fore. Draw an arrow about 5 cm. long and label it *AB*, as shown in Fig. 56. Locate as in I the image-points of *A* and *B* and label these points *A′* and *B′*. Construct with a

dotted line the image of AB. Measure the length of $A'B'$. Prolong the lines AB and $A'B'$ until they intersect. Where does this point of intersection lie? The mirror line is called in mathematics the axis of symmetry. If the paper is folded along the mirror line and if the work has been carefully done, the image will be found, when the paper is held to the light, to coincide with the object.

Compare the object with its image in a plane mirror with respect to size, distance, and form.

Question. What is the difference between the image that one sees of himself in a plane mirror and the appearance one presents to other people?

EXPERIMENT 44

IMAGES IN CYLINDRICAL MIRRORS

I. *What is the position, size, and shape of an image formed in a convex mirror?*

II. *What is the position, size, and shape of an image formed in a concave mirror?*

Convex-concave cylindrical mirror.	Ruler.
Paper.	Pins.

I. **Convex Mirror.** Place on a sheet of paper a convex cylindrical mirror so that its straight lines are vertical, and then trace on the paper the position of its convex surface. About 5 cm. in front of the mirror draw as object an arrow 4 cm. long and label it A, B, C, as shown in the Fig. 57*a*. To locate the position of the image of A, place a pin at point A so that it stands erect and then draw two sight lines along the edge of a ruler (one on each side of the pin) pointing at

the image of the pin. Label each of these lines *A*. Then stand the pin at *B* and draw, as before, two sight lines toward the image. In the same way draw sight lines to locate the image of *C*.

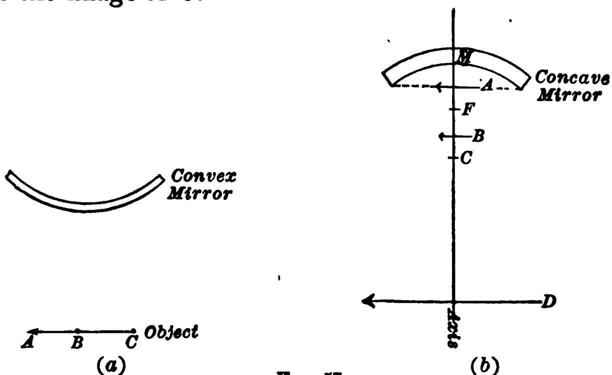


FIG 57

Remove the mirror and pin and continue each pair of sight lines until they intersect. In this way locate the image-points of *A*, *B*, and *C* and label these points *A′*, *B′*, *C″*. Draw a line from *A′* through *B′* to *C′* with an arrow at *A′*. Label this arrow the **Image**.

Compare the object and its image in a convex mirror as to position, size, and shape.

II. **Concave Mirror.** Stand the mirror a little above the middle of a sheet of paper and draw a sharp line along its concave edge. Remove the mirror and draw a dotted line connecting the ends of the arc. Draw a perpendicular at the mid-point of this chord and label it **axis**. Assuming that the radius of curvature is 5 cm., mark the **center of curvature** with the letter *C*. Mark the **focus** *F*, which is halfway between the center of curvature *C* and the mirror *M*, as shown in Fig. 57*b*. In order to locate the images of objects

at varying positions along the axis, draw a short arrow between *F* and *M* and label it *A*, another between *F* and *C* and label it *B*, and a third beyond *C* and label it *D*, somewhat as shown in the figure.

Replace the mirror on its line and observe the direction, curvature, and relative length of the images of *A* and *B*. In order to see these images more distinctly, it will be useful to draw an arrow on a small strip of paper and fold up one end so that the arrow is on the vertical part as shown in Fig. 58, and then place this strip of paper over *A* and *B*. Do the images of *A* and *B* point in the same direction as the objects?

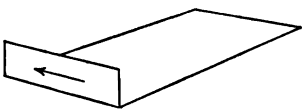


FIG. 58

To locate the position of the image of *A*, stand a pin upright at the mid-point of *A* and draw two sight lines directly at its image. Label these lines *A*, *A*. Locate the images of *B* and *C* in the same way.

When an image seems to be back of a mirror, it is said to be **virtual**, because the rays of light do not actually come from the image-point but simply look as if they had come from it. On the other hand, when as in some cases with a concave mirror the image is found in front of the mirror, it is said to be a **real image** because the rays actually do pass through the image-point.

State where the object must be placed in order to get a virtual image and where to get a real image.

State where the object must be placed in order to get an image pointing in the same direction as the object and where to get a reversed image.

State where the object must be placed in order to get an image which is smaller than the object and where to get a larger image.

Question. What would one observe if he stood at first close in front of a concave mirror and then gradually moved away from it?

EXPERIMENT 45

INDEX OF REFRACTION OF GLASS

What is the relation between the speed of light in air and in glass?

Rectangular glass plate.	Protractor.
Paper.	Pins.
Ruler.	Millimeter paper scale.

Lay a rectangular glass plate on a sheet of paper in the position shown in Fig. 59 and trace with a sharp pencil the edge of the glass. Stand a pin upright at A, touching the edge of the glass.

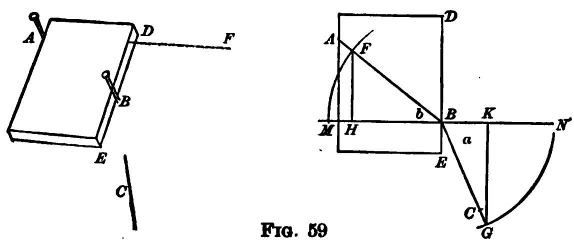


FIG. 59

If one places one's eye on a level with the paper and looks *into* the edge DE, the portion of the pin A seen through the glass seems to be in line with the part seen over the glass *only* when the eye looks into the glass in the direction FD, perpendicular to the edge DE.

In order to show just how much a ray of light is bent in passing from glass to air, place a second pin B close to the

edge DE as shown in the figure. Now move the head slowly to the left until the pin B just covers the image of pin A seen through the glass. Place a ruler so that one edge points directly at B and the image of A seen through the glass, and then draw the sight line C.

Remove the glass, and connect the points A and B, which line represents the direction of a ray of light through the glass. Prolong the sight line until it strikes the point B. This sight line shows the direction of the ray AB after leaving the glass.

The refraction of light in passing from glass into air depends on the relative speeds of light in glass and air. If we erect a normal MN at B perpendicular to DE, we find that the angle in air is greater than the angle in glass. It has also been found that *the speed of light in air is to the speed in glass as the* **sine of the angle** *in air is to the* **sine of the angle** *in glass.* To get this ratio of the sines of these angles, lay off on AB and BC equal distances (the longer the better), such as BF and BG, and draw FH and GK perpendicular to the normal MN. The sine of angle a is GK/BG and the sine of angle b is FH/BF, but since $BF = BG$,

$$\frac{\text{sine} \angle a}{\text{sine} \angle b} = \frac{GK}{FH}.$$

In short, to get the **index of refraction** of the glass used in this experiment, *i.e. ratio of speed of light in air to speed of light in glass*, we have merely to divide the length of GK (measured to tenths of a millimeter) by the length of FH.

To make a second trial, move the position of pin A to a new point A' along the edge of the glass and repeat the experiment.

Question. The index of refraction of water is 1.33. Does this mean that water refracts light more or less than glass?

EXPERIMENT 46

FOCAL LENGTH AND CONJUGATE FOCI OF A CONVERGING LENS

How far is the picture of a distant object from a convex lens? What relation exists between the object-distance and the image-distance when the object is near a convex lens?

Optical bench (Fig. 60) (meter stick and supports).
Screen with wire netting.
Double convex lens (f. 10–15 cm.).
White cardboard screen.
Holders for lens and screen.
Electric or gas lamp.

I. **Focal Length.** An object which is 100 feet or more away sends to a lens rays that are practically parallel, *i.e.* rays from any distant object-point to different parts of the lens are very nearly parallel. These parallel rays converge at a point called the **principal focus** and the distance between the lens and the principal focus is called the **focal length.**

Set the double convex lens and the cardboard screen on a simple optical bench (Fig. 60) and hold the bench in the

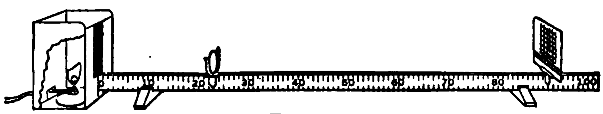


FIG. 60

back part of the room but pointing at some distant object out of the window. Having placed the lens on one of the main divisions of the meter stick, move the screen toward and away from the lens until the most distant bright object which can be seen through the window is sharply focused on the screen, *i.e.* forms a clear picture. Read and record the positions of lens and screen.

Move the lens to a new position on the stick, and again make a new setting of the screen in the same way as before. After making a third trial, find the average of the three focal lengths and record this as the focal length of the lens.

II. **Relations of Object and Image.** Set up the optical bench as shown in Fig. 60, so that the object (an illuminated wire netting) is away from the window. Place the cardboard screen at the opposite end and darken the room. Slide the lens back and forth between this screen and the object until a position is found where the picture of the netting appears on the screen as sharp as possible.

Is the image larger or smaller than the object?

Cover one part of the object and *see if the image is erect or inverted.*

Without moving the object or the screen, try to find another position of the lens that will give a sharp image.

Is it smaller or larger than the object, erect or inverted?

When the image is smaller than the object, which is nearer the lens, the object or the image?

When the image is larger than the object, which is nearer the lens, the object or the image?

Read the position of the object, lens, and image on the meter stick as accurately as possible, and record in tabular form as follows:

Positions			Object-distance	Image-distance	$\frac{1}{\text{Obj.-dist.}} + \frac{1}{\text{Im.-dist.}}$	$\frac{1}{\text{Focal Length}}$
Object	Lens	Image				

Move the screen up nearer the object and again find two positions where the lens forms a sharp image.

Continue to move the screen up closer to the object until it is possible to get only one distinct image. *What is the shortest distance between object and screen, at which the lens will form a distinct image? How many times the focal length of the lens is this minimum distance between object and image?*

Compare the sum of the reciprocals of the image- and object-distances with the reciprocal of the focal length.

Problem. What is the focal length of a lens if the image of an object 10 ft. away is 5 in. from the lens?

EXPERIMENT 47

SIZE AND SHAPE OF A REAL IMAGE

Is the real image of a straight line formed by a convex lens straight or curved; and if curved, does its center bend toward or away from the lens?

How are the image-distance, object-distance, length of image, and length of object related?

Strip of paper (about 20 × 75 cm.).
Meter stick.
Double convex lens and holder.
Block with vertical line.
Block with bent wire.

Lay a strip of paper on the table so that the long side extends toward the window. Draw a line down the middle of the paper and near the end farthest from the window, draw an arrow about 10 cm. long. Divide the arrow into four equal parts and mark the points of division 1, 2, 3, 4, and 5 as shown in Fig. 61. On the long line, mark the position of the lens, which should be distant from point 3 of

the arrow from one and a half to two times the focal length of the lens ; that is, if the lens has a focal length of 12 cm., place it from 18 to 24 cm. from the center of the arrow.

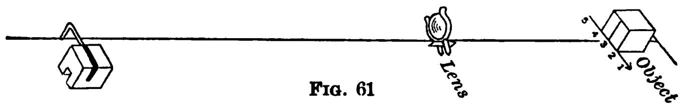


FIG. 61

Place the lens so that its center is directly over this point and its plane at right angles to the line. To locate the image-points corresponding to each of the five points of the object, stand the vertical line of the wooden block directly over point 3, and using one eye only, look into the lens from the other end of the paper so as to see the image of the vertical line. Move the block carrying the bent wire until the vertical part of the wire just covers the image. To see the wire and image distinctly, the eye should be about 30 cm. away from the wire. Move the wire to and from the lens until a position is found where, as the head moves slowly from side to side, the wire and the image keep exactly together, showing that each is at the same distance from the eye. As soon as this position is sharply determined, mark a dot directly under the point of the wire and label it 3′.

Move the vertical line along to 4 and locate in the same way the position of its image 4′. In this manner determine the position of the image of *each* of the five points of the object arrow. In locating these points it is quite essential that the observer should not let any preconceived notion as to the proper position of the image-points affect his judgment as to where each image-point *really is.*

Connect the image-points 1′ and 2′ and 3′, etc., with straight lines to get a rough idea of the shape of the whole image. Draw a straight line from each object-point to its corresponding image-point. *Where do these lines intersect?*

Connect the ends of the image arrow by a straight line, measure its length, and call it L_i. Measure the distance of the lens from the center of the object and the distance of the lens from the point where the straight line joining the ends of the image crosses the axis, and call these distances D_o and D_i respectively.

Call the length of the object L_o, compute the value of the ratio $\frac{L_i}{L_o}$ which is called the magnifying power of the lens. Also compute the value of the ratio $\frac{D_i}{D}$ and compare this result with the magnifying power. (Express the ratio to three significant figures.)

Does the center of the image bend toward the lens or away from it?

To explain this curvature of the image consider D_o for point 1 and D_o for point 3. Then, if the lens formula $\left(\frac{1}{D_o}+\frac{1}{D_i}=\frac{1}{f}\right)$ holds true, and f is a constant for the lens, what would be expected of D_i for point 1 and D_i for point 3?

How is this defect in a lens corrected so as to give what the photographers call a "flat image"?

Problem. A lantern slide picture 3 inches long is to be projected on a screen 30 feet away so as to form a picture 6 feet long. What must be the focal length of the lens? How far from the slide must the lens be placed?

EXPERIMENT 48

MAGNIFYING POWER OF A SIMPLE LENS

How many diameters does a converging lens seem to magnify an object?

Meter stick.
Double convex lens (f. 2.5–7.5 cm.) and holder.
Paper millimeter scale.
Black cardboard with square hole and holder.

In many optical instruments a double convex lens is used as a simple microscope or magnifying glass. For the average person the distance of most distinct vision is about 25 cm. (10 in.), but with a magnifying glass, the distance between the lens and the object is made a little less than the focal length and so adjusted that an erect enlarged virtual image is formed about 25 cm. away. To get the magnifying power of a simple microscope we have to find the ratio of the size of the image to the size of the object. This is, however, equal to the distance of the image divided by the distance of the object, that is, $25/D_o$ where D_o is the object-distance in centimeters.

First find the focal length of the lens by holding a meter stick horizontally with one end against a piece of white cardboard and with the other end pointing at some distant object outside the window. Hold the lens in the hand and move it slowly away from the screen until it forms a clear picture. This distance between the lens and the screen is the focal length of the lens. Record the focal length and number of the lens.

Place a paper millimeter scale on the table and stand a meter stick upright on it. At a distance of 25 cm. fasten a short focus lens to the meter stick. Then just under the